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BENEFIT ASSESSMENT OF

NASA SPACE TECHNOLOGY GOALS

FINAL REPORT

July 26, 1976

This report was prepared under Contract No. NASW-2911
to the National Aeronautics and Space Administration

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OUTLINE OF THE FINAL REPORT

Socio-Economic Assessment of Space Applications

I. Introduction
   A. Purpose of the Study and this Report
   B. Description of the Approach
   C. Summary and Conclusions
   D. Structure of this Report

II. National Needs, NASA Themes and Space Technology Goals
   A. National Needs
   B. NASA Themes
   C. Space Technology Goals

III. Major System Applications

IV. Socio-Economic Assessments of Selected Applications
   A. Overview of Benefit Assessments
   B. Electronic Mail
   C. Personal Telephone Communications
   D. Weather and Climate Monitoring, Prediction and Control
   E. Crop Production Forecasting and Water Availability
   F. Planetary Engineering of the Planet Venus
   G. Planetary Exploration

V. Summary

References

I. INTRODUCTION

A. Purpose of the Study and this Report

This study was sponsored by the NASA Office of Aeronautics and Space Technology (NASA/OAST) and undertaken by JWK International Corporation to provide an assessment of the socio-economic benefits to be derived from system applications of space technology goals developed by NASA to satisfy national needs. The study involves three principal analytical tasks. The first -- Review of NASA/OAST Space Technology Goals -- was structured to determine the extent of capabilities and limitations associated with the goals. The second -- Identify Systems Applications -- was designed to identify significant systems applications of each space technology goal in terms of potential benefits related to a specified set of National Needs. The third task -- Evaluate Potential Benefits -- was designed to provide a gross assessment of the socio-economic benefits to be derived from selected system applications.

Results of the first task were reported to NASA/OAST with a briefing and presentation of working papers on April 8, 1976. Subsequent discussion provided further guidance for the pursuit of the remaining tasks.

An interim report was presented to NASA/OAST on June 4, 1976 which reported progress to date and completion of the second task. It described the process and rationale employed to identify and categorize thirty-eight major system applications. Ten applications were selected for further consideration, according to the following criteria:

- the satisfaction of National Needs
- the technological feasibility of accomplishment
- their relation to Space Technology Goals, and
- the feasibility of socio-economic benefit assessment.

The ten candidate applications were:

1. Electronic mail
2. Personal telephone communications

3. Weather and climate monitoring, prediction and control
4. Power production and dissemination for terrestrial utility
5. Crop production forecasting and water availability
6. Space processing and production
7. Earth science
8. Formation and evolution of the Solar System
9. Nature and causes of solar activity
10. Search for extraterrestrial intelligence.

NASA/OAST selected candidates 1, 2, 3, and 5 from the above recommended list and nominated two others -- Planetary Engineering, specifically modification of the atmosphere of the planet Venus and Planetary Exploration.

B. <u>Description of the Approach</u>

The six selected areas for evaluation and analysis were:

1. Electronic Mail
2. Personal Telephone Communications
3. Weather and Climate Monitoring, Prediction, and Control
4. Crop Production Forecasting and Water Availability
5. Planetary Engineering of the Planet Venus
6. Planetary Exploration

Benefit assessment of the selected system applications was pursued through a sequence of stages with variations of content or details as appropriate to each. First, a system description was prepared in sufficient detail to permit an evaluation of technical feasibility and to serve as a basis for defining and estimating benefits. These system descriptions were based primarily on applications from the <u>Outlook for Space</u> and related literature. When examination of feasibility revealed a technical limitation, it was described and the system description amended to achieve feasibility. This included recommendations for system improvements as necessary or appropriate. Preliminary estimates of development and operations costs were made especially when this information was needed for the benefits assessment.

Then, each system application was examined in terms of relationships to the national needs. It was decided to concentrate on socio-economic benefits

that would contribute to six of the Needs -- Economy, Energy, Environment, Protection of Life and Property, Food and Natural Resources, and New Knowledge. Contributions to Defense were considered, and included where appropriate.

Next, a full cataloging of potential socio-economic benefits was undertaken. In its first stage, there was no concern for quantification. The emphasis was placed on developing a wide range of conceivable benefits for each application. Later, the search for data and the process of estimating the magnitudes of benefits was pursued. The data search was spread beyond libraries and technical literature. Inquiries were addressed to association researchers, academicians, businessmen, civil servants, and others -- wherever clues led and the phone reached. Keen interest and willing cooperation was the usual response but some searches did not succeed. Some other inquiries had to be curtailed as time passed. Insofar as possible, potential benefits were estimated from recorded data. Often, the judgment of experienced analysts was used to amplify on limited data - always seeking objectivity and reasonable magnitudes. When impossible to quantify a benefit -- from lack of data or time -- qualitative descriptions were made.

These system descriptions and benefits assessments are the principal product of this study. They are presented in Chapter IV of this report in the form of case studies.

C. Summary and Conclusions

1. Electronic Mail

- The technology required for the electronic mail system will be available within a decade. The system could be tested within 5 or 6 years and fully implemented by 1990.
- The need for faster, more reliable, and less costly mail service is pressing.
- For nationwide service, the system will require three geosynchronous satellites, with periodic replacements, and about 25,000 transmitter-receiver stations in Post Offices.

- Development costs will approximate $12 billion during the initial six years. Annual operating costs of $4.62 billions are dominated by personnel costs, most of which will be spent for mail service whether or not this system is developed.

- Substantial socio-economic benefits will accrue to the nation, its industry, and its people.

- The system recommends itself for near-future development and implementation.

2. Personal Telephone Communications

- A personal communications system, using geosynchronous satellites with large antennae and small personal transceivers, is feasible with expected technological advances.

- It will require communications satellites of uncommon size, requiring a space shuttle system and capability for assembly in space.

- System development and experimental phases would cost about $160 million. Implementation costs will approximate $300 millions and, annual operations costs of $10 million are estimated. The program could begin by 1983 and be operational by 1990.

- The personal communication system will produce substantial social and economic benefits, expected to surpass $640 millions per year.

3. Weather and Climate Forecasting, Monitoring and Control

- By 1985, an operational system could be implemented, based on the GARP global experiment. The network would include 2 to 4 satellites in near-Earth, Sun-synchronous and geostationary orbits. Existing facilities for weather and climate observations would be incorporated.

- The effects of weather and climate are universal. Longer range and accurate forecasts of weather and climate changes will be totally pervasive. Such forecasts will improve crop productivity, reduce losses of life and property, create new industries, improve safety, reduce costs of public planning efforts, and benefit many other undertakings.

- The potential socio-economic gains of improved weather and climate forecasting are so great that the recommendation for continued development of this capability is emphatic.

4. Crop Production Forecasting and Water Availability

- Satellite systems offer a feasible and systematic approach to greatly enhanced capabilities for crop forecasting, resource management, and water inventory observations.
- Increasing world food needs, declining surpluses, and rising prices will require major efforts to increase productivity of food production and water management - to sustain our economy and to help other nations.
- The system will involve multi-sensor satellites, other earth- and atmosphere borne sensors, large data transmission and processing capabilities, optimal sampling strategies, sensors with high signal-to-noise ratios, large antennae in space, and further improved predictive models.
- Economic benefits from improved management of earth resources may easily exceed $2 billion annually. Social benefits may be even greater. The satellite systems would cost only a fraction of such sums.
- This system is needed, its implementation should be pursued urgently.

5. Planetary Engineering of the Planet Venus

- The ability of man to alter the atmosphere and surface of Venus so that the planet will sustain human, animal, and plant life appears to be feasible.
- Such a development may, in the next millenium, be required for the further existence of the human race.
- The seeding of the Venusian atmosphere with certain spores of blue-green algae, with supporting photosynthesis, seems to be the most feasible way to effect the changes.
- The costs of starting such a project would be minimal for several years. The entire project costs should be somewhat less than $20 B dollars.
- It is recommended that the first phase, laboratory studies and experimentation be started in the near future. The further implementation of the program would take place at an appropriate time.

6. Planetary Exploration

- A three-phase planetary exploration program is needed over the next few decades
- The first phase, reconnaisance, already under way, will be completed before the end of the century
- The exploration phase will also be completed by the end of the century
- The intensive study phase will be underway by this time
- During the twenty-first century the intensive study phase will continue, and exploitation and colonization of certain planets and satellites will proceed.

D. Structure of this Report

The remainder of this report is organized as follows.[1/] Section II presents a discussion of National Needs, NASA Themes, and their interrelationships. The third Section identifies Major Applications of Space Technology, and their relationships to NASA Themes and National Needs. Section IV includes the socio-economic benefit assessments for the six selected system applications. The final Section presents a brief summary of potential benefits from the selected Space System Applications, as related to National Needs.

1/ Some subject matter from the interim report has been repeated here to make this report more self-sufficient.

II. NATIONAL NEEDS, NASA THEMES, AND SPACE TECHNOLOGY GOALS

A. National Needs

For purposes of this study, seven National Needs were provided to us by NASA/OAST. These are:

1. Economy
2. Energy
3. Environment
4. Protection of Life and Property
5. Food and Other Natural Resources
6. Defense
7. New Knowledge

In the balance of the report, we have related these National Needs to the major system applications that have been developed.

B. NASA Themes

NASA/OAST supplied us with six Themes to use in structuring this report. These are:

1. Global Service Systems
2. Space Power Platforms
3. Industrialization of Space
4. Advanced Space Transport Systems
5. Exploration of the Solar System
6. Search for Extraterrestrial Intelligence

A discussion of the objectives of each Theme and a brief description of each system follows:

1. Global Service Systems

The purpose of Global Service Systems will be to enable practical global observations and operations services through a 1000-fold increase in the ability to acquire, process, and disseminate useful information for a wide variety of applications at less than current costs.

A series of large multipurpose satellites will be placed in low-Earth or geosynchronous orbits. They will have highly-developed observational sensors

for data acquisition; improved data processing, switching, storage, and communication capability; and advanced power generation equipment. They will be capable of autonomous operation for long periods of time.

2. Space Power Platforms

The objective of the Space Power Platform Theme is to provide, in an evolutionary process, the power needed for operation of space vehicles and stations, for space manufacturing, and for laser propulsion systems. Ultimately, the systems would provide the capability of generating power in space and transferring it to Earth for terrestrial utility.

Large space power platforms will be placed in geosynchronous or low Earth orbit. Advanced solar power generation systems, including large solar arrays, will be required as well as advanced radioisotope thermoelectric generators. Advanced energy storage will be required. Power transmission would be by microwave and high-power laser beams. Large ground-based rectennas would ultimately be required.

3. Industrialization of Space

The purpose of this Theme is to develop the technology to provide practical exploitation and utilization of space. This technology will permit the fabrication and assembly of large structures for orbiting and lunar habitats.

Facilities will be provided in space for manufacturing, development and processing of biologicals and other materials for earth consumption, and scientific and medical research. Lunar bases will be established to exploit any potential benefits to be derived from the Moon. There will be facilities in space for carrying out toxic or otherwise hazardous processes. Ultimately, space hospitals could become a reality.

4. Advanced Space Transportation Systems

In order to construct the facilities and provide the long-term logistical support for future space activities to benefit mankind, transportation systems which have high performance capabilities and low unit and mission costs must be developed.

Some of the technological developments required to meet this goal are: (1) to improve space structures by using new material combinations to achieve structural weight reductions; (2) to increase the efficiency of propulsion systems and fuels; (3) to increase the reliability of and reduce power requirements for on-board electronic systems; (4) to increase the capacity for data acquisition, processing, storing, and transmission; and (5) to increase the power density of space power systems.

5. Exploration of the Solar System

The purpose of this Theme is to increase mankind's knowledge of the evolution, dynamics, and physical and chemical characteristics of the sun, planets and their satellites, asteroids, comets, and interplanetary material and cosmic rays.

This would require a coordinated program between NASA and other space agencies and world-wide observatories and other astronomical installations.

The system to accomplish this objective could include: (1) manned and unmanned Earth-orbital instrumented spacecraft; (2) advanced solar probes and sun-orbiting satellites; (3) advanced lunar exploration and the establishment of lunar bases; (4) visits to comets and asteroids; (5) planetary manned and unmanned fly-bys, orbital flights, and landings; and (6) Earth, lunar, and planetary-based astronomical and detection instruments.

6. Search for Extraterrestrial life

From Stephen H. Dole Habitable Planets for Man:

> "within one hundred light years of the earth (a relatively small distance when it is considered that the thickness of our galaxy is over ten thousand light-years at the center and its diameter is about eighty thousand light-years), there should be about fifty habitable planets."

The purpose of this Theme is to define a long-term program to detect and communicate with intelligent life elsewhere in the universe. We must also transmit intelligible signals ourselves, since other civilizations would also be looking for signals.

The system would include: (1) Earth-based and orbital processors and facilities capable of receiving, identifying, and processing signals from other civilizations; (2) equipment to transmit intelligible signals from Earth into deep-space; (3) large arrays erected on the moon or asteroids; and (4) long-life spacecraft to probe outside the solar system.

C. Space Technology Goals

The following space technology goals have been specified to JWK International by NASA/OAST for use in the present study.

SUPERGOAL: To enhance future space systems by a 1000-fold increase in effectiveness.

1. INFORMATION ACQUISITION: A ten times increase in capability to provide a capacity of 10^{16} bits/year.

2. SPACE STRUCTURES: The capability of providing ten times larger structures up to one kilometer in diameter.

3. POWER CAPACITY: To provide five times the power capacity up to 200 watts/kilogram and 100 watt-hours/kilograms.

4. INFORMATION MANAGEMENT: A 1000-fold increase in capability to handle up to 10^{16} bits/year.

5. PROPULSION EFFICIENCY: A 1000-fold increase in efficiency to provide the capability of 10^5 kilograms/year.

6. TRANSPORTATION COSTS: To cut costs by a factor of ten to provide $50 /pound to low earth orbit and $500 /pound to geosynchronous earth orbit.

7. SPACECRAFT COSTS: To cut costs by a factor of ten so that the yield is 8¢/megabit.

8. MISSION SUPPORT COST: To provide mission support at one-half the present cost.

9. SOFTWARE COSTS: To cut costs by a factor of ten to 2¢/megabit.

Figure 1 relates the NASA/OAST Space Technology Goals to the NASA Themes.

SUPERGOAL	TO ENHANCE FUTURE SPACE SYSTEMS BY A 1000-FOLD INCREASE IN EFFECTIVENESS								
SYST TECH GOALS	Information Acquisition 10-Fold Inc. 10^{16} Bits/Yr.	Space Structures 10x Larger 1 Km.	Power Capacity 5x Increase 200 Watts/Kg 100 Watt-hr/Kg	Information Management 1000-Fold Inc 10^{16} Bits/Yr	Propulsion Efficiency 1000-Fold Inc 10^{16} Bits/Yr	Transportation Costs 10-Fold Dec \$50/Lb to LEO \$500/Lb to GEO	Spacecraft Costs 10-Fold Dec 8¢/MB	Mission Support Costs 50% Dec.	Software Costs 10-Fold Dec 2¢ MB
THEMES									
Global Service Systems	X	X	X	X	X			X	X
Space Power Platforms		X	X			X	X		
Industrialization of Space		X							
Advanced Space Transport Systems			X		X	X	X	X	
Exploration of the Solar System	X		X	X	X		X	X	X
Search for Extraterrestrial Intelligence	X	X		X		X	X		X

FIGURE 1: THEMES VS. SPACE TECHNOLOGY GOALS

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III. MAJOR APPLICATIONS OF SPACE TECHNOLOGY

In Task II of this study we identified and categorized thirty-eight major system applications. We repeat these herein for completeness and possible future planning purposes. We divided these into eight categories as follows:

1. Communications and Information Flow
   a. Telephone-type communications
   b. Large-scale information handling
      (1) air traffic control
      (2) railroad locator
      (3) ship locator
      (4) library materials
      (5) legal information
      (6) government and business data
      (7) law enforcement data
      (8) health and safety data
      (9) military status information
   c. Electronic mail
   d. World-wide television
      (1) for commercial use
      (2) for entertainment
      (3) for education

2. Global monitoring, prediction, and control
   a. Weather and climate
   b. Radiation and solar events
   c. Earth phenomena warning
   d. Transportation control
   e. Military deployments

3. Power production and dissemination
   a. Power for operations of space vehicles and stations
   b. Power for terrestrial utility
   c. Power for space manufacturing
   d. Laser propulsion for aircraft or spacecraft

4. Resource exploration and development

    a. Crop production
    b. Metallic deposits
    c. Petroleum resources
    d. Water availability
    e. Ocean resources

5. Space processing and production

    a. Biologicals
    b. Other materials
    c. Electronic components and devices
    d. New commercial products
    e. Hazardous processes
    f. Space hospitals

6. Earth and atmospheric science

    a. Earth's magnetic field
    b. Crustal dynamics
    c. Ocean interior and dynamics
    d. Structure, chemistry, and dynamics of the atmosphere
    e. Space medicine

7. Exploration of the Solar System

    a. Formation and evolution of the Solar System
    b. Atmospheric dynamics
    c. Origin and history of magnetic fields
    d. Nature and cause of solar activity

8. Exploration of the Universe

    a. Search for extraterrestrial intelligent life
    b. Origin, evolution, and dynamics of the Universe
    c. Nature of quasars, pulsars, and stellar explosions
    d. Nature of interstellar matter and cosmic rays
    e. Size of the universe - finite or infinite

Figure 2 relates these applications to National Needs and NASA Themes.

SUPERGOAL	TO ENHANCE FUTURE SPACE SYSTEMS BY A 1000-FOLD INCREASE IN EFFECTIVENESS						
NATIONAL NEEDS / THEMES	ECONOMY	ENERGY	ENVIRONMENT	PROTECTION OF LIFE AND PROPERTY	FOOD AND OTHER NATURAL RESOURCES	DEFENSE	NEW KNOWLEDGE
Global Service Systems	1.a.b.c.d. 2.a.c.d. 4.a.b.c.d.e.	4.c.d.e.	2.a.b.c. 4.d.e. 6.a.b.c.d.	1.a. 2.a.b.c.d. 6.e.	2.a.c 4.a.b.c.d.e.	1.a.b.d. 2.a.b.c.d.e.	2.a.b. 4.a.b.c.d.e. 6.a.b.c.d.e.
Space Power Platforms	3.a.b.c.	3.a.b.c.d.		3.c.	3.c.	3.c.	
Industrialization of Space	5.a.b.c.d.		5.e.	5.e.f.	5.a.d.	5.c.	5.a.b.c.
Advanced Space Transport Systems	Supports all other themes and needs						
Exploration of the Solar System	7.a.b.c.d.	7.a.c.d.	7.b.c.d.	7.b.d.			7.a.b.c.d.
Search for Extraterrestrial Intelligence	8.a.b.c.d.e.	8.c.d.					8.a.b.c.d.e.

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FIGURE 2: RELATIONSHIP OF MAJOR APPLICATIONS TO THEMES AND NATIONAL NEEDS

IV. MAJOR SYSTEM APPLICATIONS

A. Overview of Benefit Assessments

This document presents a highly focused analysis of several sociotechnic systems built upon space technology and a prediction, perhaps bold, on their social and economic effects on American society.

Our approach was to search for and identify the most compelling ways these systems would impact socially and economically upon our society, and, from this effort to present a catalogue of major gains from each system. The most substantial benefits provided by each system are discussed. But by no means, is every benefit scrutinized for possible indirect or intangible ramifications.

The estimates which are described here are not precise, partly because of the time and resources permitted by this study and, more importantly, because of the difficulty in quantifying such complex and diffuse consequences attributable to advanced technological systems operating in a highly developed industrial society. A word of caution is offered concerning the occasionally subjective nature of an analysis such as this. These systems offer many conveniences to their users. But "convenience" has many different meanings to the consumer. Yet the expectation of greater convenience is responsible for the sale of many hundreds of millions of dollars in goods and services. Any attempt to quantify a benefit such as this presents many problems and in some cases, only a qualitative description of the benefit is given.

The systems investigated in this report to a great extent complement and augment each other. Weather prediction capability controls the limit of improved crop yield forecasting. This new technology will make operational

many of the systems not included in this investigation. The overlapping of some of these systems makes an exhaustive study of the socioeconomic impacts of each separate system redundant. Better understanding is achieved through examining ways in which the consumer is most importantly effected. Stated another way, each of the systems, described in the material which follows, represents only a fraction of the influence resulting from acting together.

Operating thus as a synergism, the study of only a small part of a much larger aggregation of space technology applications undervalues the total impact of the whole. Mindful of this limitation, the reader will better appreciate the material which follows.

ELECTRONIC MAIL

TABLE OF CONTENTS

Application: Electronic Mail

Background:

The U. S. Postal Service has had problems for many years. Postal rates have steadily risen -- from 4¢ per first class letter to the present 13¢ -- during the past twenty years. Second and third class rates have also risen dramatically. In spite of this large increase in costs, improvements in mail service have not kept pace. The widespread use of zip codes, the increase in the use of semi-automated equipment, and the addition of personnel have not stemmed the tide. Deliveries are still late and misdirected; delivery schedules have, in many cases, been curtailed; and the public has been withdrawing its business from the mail system and turning to other means of communication -- telephone, wire services, messengers, and private delivery services. Although overall communications have risen, there has been a per capita decrease in pieces of mail handled by the Postal Service since 1971. As volume drops, rates are raised to recover the lost revenue. The higher rates produce a greater loss of revenue.

It has been the hope of the American people that the U. S. Postal Service could, in time, be self-sustaining. In creating the new U. S. Postal Service in 1969, President Nixon said: "The will of the Congress and the will of the people is clear. They want fast, dependable and low-cost mail service. They want an end to the continuing cycle of higher deficits and increasing costs." In the past seven years, little improvement has been evident.

In the next decade, the U. S. population will grow at a great rate; the need for communications will increase. By improvements in management and operating procedures, by taking advantage of modern sorting technology, and by standardizing envelope size and zip code envelope locations, the present U. S. postal system may be able to provide adequate service for many years. However, costs and deficits may still rise. There is also the possibility that the requirements may grow to such an extent that the system is unable to cope with the situation.

Electronic first class mail is a tool that could alleviate the difficulty. It could probably handle any possible increase in first class requirements along with providing a non-deficit posture for this part of the problem.

Objective

By the year 1990, projected advancements in technology will make it possible to transmit all first class mail between post offices in the United States via communications satellites. Such a system will provide fast, dependable, and low-cost mail service. Provisions will also be made to provide private mail delivery, however, at premium rates.

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Technical Background

There are five significant advanced technology projections which will make this possible (see the Forecast for Space Technology). Looking forward to the year 1990:

- The transfer-rate from a communications satellite in geosynchronous orbit to Earth via microwaves will be about 10^{10} bits/second.

- The transfer-rate from a communications satellite in geosynchronous orbit to a small earth terminal with a 60-centimeter antenna will be in the order of 10^8 bits/second.

- Commercial communications satellite transmission costs will be dramatically reduced so that the annual cost per voice circuit will be in the neighborhood of $20.

- The capacity of spaceborne mass storage systems will be about 10^8 megabits.

- The transfer-rate of spaceborne mass storage systems will be about 10^8 bits/second.

Preliminary System Description

1. Space System

The space system will consist of one or two communications satellites in geosynchronous orbit 32,5000 kilometers above the equator west of Quito, Ecuador. Each satellite will have the capability of receiving, switching, and retransmitting large amounts of data between approximately 25,000 small Earth terminals. Mass data storage systems will be provided to handle peak-load periods or other unusual conditions.

2. Ground System

There will be approximately 25,000 earth terminals (individual post offices) equipped with 60-centimeter antennas and electronic equipment. Each will be able to prepare mail for electronic transmission, to transmit the information to the satellite, and to receive and process the retransmitted data.

3. System Operation

There are several options available for moving mail from the Originator to the Addressee. Some of these are shown in Figure 1.

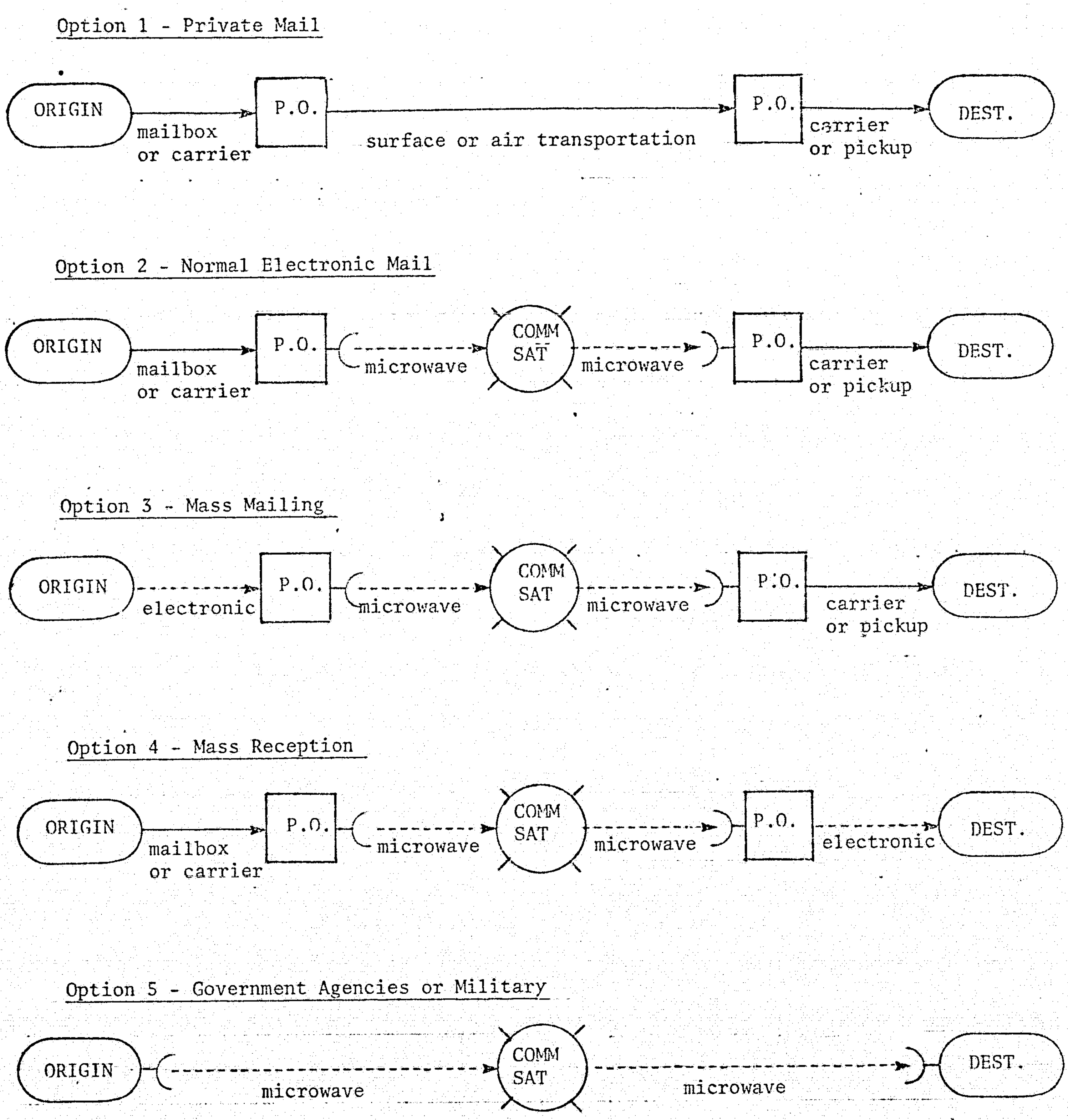

FIGURE 1: ELECTRONIC MAIL - SYSTEM OPTIONS

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Option 1.

First class mail is sent from the Originator to the Post Office by carrier or deposited in a mailbox. It is then sent by surface or air transportation to the receiving Post Office and to the Addressee by carrier or pickup. This is essentially the same process as in our present system and, in the Electronic Mail System, would be used for private mail. This would be a premium service. This option would also be used for local mail, that is, within the jurisdiction of one post office or city, at no premium.

Option 2.

First class mail is moved from the Originator to the Post Office as before. The Post Office prepares it for transmission and sends it via microwave to the communications satellite where it is switched, amplified, and retransmitted to the receiving Post Office. The receiving Post Office then processes the mail for delivery to the Addressee by carrier or pickup. This would constitute the normal operation for handling first class mail.

Option 3. Mail is transmitted from the Originator to the Post Office electronically. This option would be used largely by government or industry for mass mailings on a subscription basis.

Option 4. Mail is received by the Addressee electronically. Again, used for mass reception, this service would be provided to government or industry on a subscription basis.

Option 5. This option would be used primarily by government agencies or military departments. Each terminal would be able to communicate with the others directly through the communications satellite. Each such user would have an antenna and electronic system similar to that of the post offices.

4. Normal Operation

Since Option 2 is the normal operation, we will discuss it in some detail.

Preparation by the Originator:

The Originator, whether an individual or an organization, must prepare mail in a standard but flexible format. One possible format is depicted (Figure 2). The forms may be purchased from a post office, at a nominal price, or from a stationer if a letterhead is desired. The important thing is that everything on the form must be machine readable.

The Originator, in preparing his mail, has a great deal of flexibility. It can be handwritten or typewritten, can include diagrams and figures as well as prose, but it must be electronically readable. Marked-sense pencil or electronic ink, whether handwritten or typewritten must be used.

Stamps or registration number could then be affixed. However, there are many options available for remuneration to the Postal Service. These will be discussed later.

STAMP OR REGISTRATION NUMBER

SENDER:	ADDRESSEE:
Name Address City, State ZIP: (or letterhead)	Name Address City, State ZIP:

TEXT

Signature

#End of Message

FIGURE 2: ELECTRONIC MAIL FORMAT

The material is then put in an envelope or simply folded. The sender can put it in a mailbox or hand carry it to the Post Office (any post office will suffice).

Post Office Preparation:

The sending Post Office prepares the day's mail for transmission to the satellite as follows.

The piece of mail is removed from its envelope or unfolded and placed in a pile. The operator reads the Addresse's zip code and, using a writer with electronic ink, puts this number in the Destination Code position. This number is the first thing the satellite will see and will determine the post office to which it will retransmit the message.

In this process, the operator will separate local mail for delivery in the regular manner. The operator will also set aside those pieces for which the zip code is missing and will fill them in later.

At the appropriate time for transmission, the operator places the pile of mail in the hopper of its code-send equipment. As each piece is read in, it will be coded into television-type format and transmitted to the communications satellite.

The Originator's material is then destroyed. Some verfication feedback could be considered.

Communications Satellite Operations:

The communications satellite will accept each piece of mail, determine the outgoing channel by sensing the Destination Code, and retransmit the message to the destination Post Office -- still in television format. During peak-load periods, the satellite may read some of the mail into mass storage for later retransmission.

Receiving Post Office:

As each page is received in the receiving Post Office, it is reproduced from the television format on a piece of paper. This is placed in an envelope and sent to the Addressee via carrier or picked up at the Post Office by the Addressee.

The Addressee will receive a complete facsimile of the Originator's letter whether handwritten or typed.

5. Outstanding Operational Problems

There are several technical problems that face the development of an electronic mail system. These include:

- Frequency allocation
- Queuing. The proper scheduling between the satellite and the post offices.
- Transmission of photographs, etc. This would probably be done by premium first class mail (option 1).
- Check transmission. For the payment of bills, either an Electronic Fund Transfer program must be instituted, or our legal system would have to recognize a transmitted check as valid.
- Postal Department remuneration: stamps, registration numbers, subscriptions, or some other means.
- Disposal of paper at post offices. Double the amount of paper would be generated. Recycling would be possible since large bulks of paper would be located at the post offices.

Preliminary Systems Analysis

The following is a gross analysis of the data flow rates and personnel requirements for an Electronic Mail System:

1. Data Flow Rates

At the present time, there are approximately 25,000 post offices in the United States handling approximately 50 billion pieces of first class mail per year. Also, in our present television system each picture is reproduced by about 240,000 bits (524 x 460).

Let us assume that, in the year 1990, the number of post offices remains the same but the volume of first class mail rises to 75 billion pieces per year. Let us also assume that each piece of mail consists of one page (240,000 bits). Then our system must be capable of handling 1.8×10^{16} bits/year. Accepting the NASA/OAST space technology goal of 10^{16} bits/year/satellite capability, which appears to be obtainable, we could handle the Electronic Mail System with two communications satellites plus one spare.

Since the transfer-rate from geosynchronous orbit to a small-earth terminal is projected, in 1990, to be 3×10^{15} bits/year, this should not be a problem. In the Electronic Mail System each post office would be required to send and receive about 7.2×10^{11} bits/year.

2. Personnel Requirements

Each post office, on the average, would send and receive 3×10^{6} pieces per year or approximately 8,200 pieces per day. On the transmitting end, each operator should be able to prepare about 8 pieces/min., or 480 pieces/hr. Suppose that 10% or 55 pieces required special handling of 2 minutes each (affixing a zip code for example). Then the operator could handle 550 pieces/hour or 4,400 pieces in an eight hour day.

It is seen that two outgoing operators, two incoming operators, plus one spare operator could handle the Electronic Mail in the average post office. Adding two maintenance people and one supervisor would require a complement of eight personnel at the average post office.

Preliminary Cost Analysis

In the following, all cost assumptions are deliberately on the high side.

1. Cost Assumptions

    - Each satellite will cost about $360M. Three will be provided initially (two operational and one space), each with an in-orbit lifetime of at least five years. Assume that one will be replaced or added to the system every three years. These costs include launch and in-orbit maintenance.

    - Each ground system will cost about $200K with 10% replacements each year. This includes spare parts, modifications, etc.

    - Eight personnel would be required at an average post office (five operators, two maintenance people, and one supervisor) at an average salary of $20K per year.

2. Ten-year Costs

    - Initial Costs

Satellites	$ 1,080M
Ground Stations	5,000M
Total	$ 6,080M

    - Average Yearly Costs

Satellite Replacements	$ 120M
Ground Station Replacements	500M
Personnel	4,000M
Total	$ 4,620M

    - Ten-year Costs

Initial Satellites	$ 1,080M
Satellite Replacements	1,080M
Initial Ground Stations	5,000M
Ground Station Replacements	5,000M
Personnel	40,000M
	$52,160M

3. Cost per Page

In ten years, the Electronic Mail System will handle 75×10^{10} pages of mail at a cost of $\$52.16 \times 10^{10}$. Therefore, the cost of each page of first class mail will be approximately 7.0¢.

Socio-Economic Benefits

Substantial benefits are expected from the development and implementation of an electronic mail system. The economy will be boosted through jobs and payrolls, domestic and export sales, consumer postal savings, and enhanced revenues and savings of the Postal Service. The system will conserve energy and encourage environmental improvement. Protection of property -- the mail -- will be increased. It will consume little of natural resources and will expand knowledge in some industrial processes. These benefits are described more fully in the following paragraphs.

1. Economy

Obviously, the electronic mail system will have direct effects on the electronics industry. It will be called upon to undertake the necessary research and development of the systems, then to produce the hardware components for 25,000 post office. Our preliminary ten-year estimate of $12.2 billions for initial and replacement systems is a conservative estimate of the impact of the electronic mail system on the communications industry. This approximates 6 years of sales for the communications industry group most likely to be affected.1/ This industry employed almost 66,000 people in 1972 with an annual payroll approximating $647 millions. Engineering and construction firms will be involved in installation of transmitter-receiver systems at 25,000 post offices. These firms range widely in size and geographic location. They will benefit from about $250 millions of the initial and replacement expenditures mentioned above.

The paper industry will experience substantial effects. The electronic mail system will generate new demand for 300,000 to 500,000 tons of paper per year. This paper will be used in translating the electronic signal into hard copy for local delivery to addressees. Such quantities of additional paper usage will generate between 1750 and 2750 new production jobs in the paper manufacturing industry. Estimated annual payrolls for these jobs will range from $28 to $43 millions.2/

These volumes of new paper demand will approximate 120 to 200 millions of reams annually. At current prices for large purchases, this will approximate $150 to $225 millions of annual sales for wholesale paper distributors. This is 3 to 4 percent of the $5.2 billions of sales for 1972 and implies a comparable increase of 850 to 1150 additional jobs and $9 to $13 millions of annual payroll.

The scrap paper industry is expected to respond with enthusiasm to the prospect of 300 to 500 thousands of tons of high-quality paper scrap to be available in predictable quantities from a relatively limited number of locations.3/ While these quantities represent only 2 to 4% of the waste paper recycled in 1972, this paper will be regarded as a prime resource by recyclers. It

1/ Commercial, Industrial and Military Communications Equipment, SIC 3662-1, 1974 value of shipments were $1,957,800,000.

2/ Estimated from data reported in Labor and Operating Statistics, 1972, American Paper Institute, April 1973.

3/ Based on phone conversations with representatives of the General Services Administration, scrap processors, and trade associations.

will be clean, of uniform content, accessible at known locations in predictable quantities, and prepared for shipping. In the current market, companies pay $26 to $28 per baled ton. Recorded sales and quantity data for the industry indicate a selling price of about $40 per ton. These quantities of postal scrap will generate industry sales of $12 to $20 millions per year. Such quantities and sale will support from 275 to 465 jobs in the industry with related annual payrolls of $1.9 to $3.2 millions.1/

The Postal Service will be able to increase its revenues by selling this desirable scrap paper. At current prices, these quantities of scrap paper would yield between $7 and $13 millions per year.

The electronic mail system will help the U.S. Postal Service to control future increases of costs and postal rates. This potential benefit is particularly difficult to quantify since this study cannot simulate the postal rate-making process and it is recognized that first-class postal rates are not based only on the costs of first-class mail service. Nevertheless, a rough approximation can be offered. This study reports an estimate of 7.0 cents per page for electronic transmission of mail. This approximates the current postal charge for a letter, at 14.0 cents for two pages. Recently, it was reported that first class postage may have to be raised to 34 cents by 1984.2/ If electronic mail could save only half of the difference (34-14 cents), the gross savings of postage to the senders of 50 to 75 billions of letters per year would approximate $5.0 to $7.5 billions per year.

There will be balancing impacts on employment in the Postal Service. The USPS will require additional engineers and technicians. A rough estimate of 10,000 engineers and 50,000 maintenance technicians would add a little more than $1 billion to the USPS annual wage and salary budget. This need not be a net addition to the wage and salary cost. The electronic mail system will displace some employees now engaged in handling and transporting long distance mail. The need for operators and technicians plus the expected growth of total mail usage will offset much or all of this displacement. At the same time, it will create new career opportunities in the Postal Service. Operating personnel required for this system most probably can be obtained by retraining USPS employees. Finally, the adjustment will not be instantaneous. There will be a period of about 5 years during which the USPS will be able to accomplish the necessary training and employment changes.

It is most probable that the demonstrated success of an electronic mail system will generate interest in other countries of the world, thus creating

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1/ From sales and quantity data for 1972, adjusted to approximate 1975 dollars.

2/ As reported by national newspapers on April 1, 1976 and attributed to the U.S. General Accounting Office.

opportunities for export sales. Possible magnitudes of such sales may be estimated from comparison of postal volumes. Recent volumes of total mail for industrialized countries of the world are summarized as follows:

Volumes of Total Mail - Industrialized Countries

Country	Period	Billions of Pieces
U.S.A.	1974-75	89.2
Australia	1974-75	2.5
Canada	1975	5.4
France	1973-74	10.5
Germany	1974	12.1
Great Britain	1973-74	11.1
Italy	1970	6.4
Japan	1973	14.1
Netherlands	1972	3.3
Switzerland	1973-74	3.6

Source: International Postal Service, U.S. Postal Service

Estimated proportions of first-class mail among these totals indicate a potential export market of from 1 to 2 of the U.S. systems described above. This indicates potential sales of $12 to $24 billions. Since these sales will occur only after the U.S. system has been demonstrated successfully and will not occur simultaneously, they are not expected to increase industrial employment, but rather to sustain increments generated earlier by the U.S. electronic mail system. These sales are likely to occur during a period of ten years.

Annual economic benefits of the electronic mail system are summarized in Table 1. Demand for additional quantities of paper, plus recycling, will generate nearly half a billion dollars of sales and support up to 4365 jobs with related payrolls approaching $60 millions. Development and implementation of the system will support continued sales, jobs, and payrolls in the communications-electronics industry for several years. Similarly, the USPS will experience employment changes and new opportunities. These are not projected as new employment. Also, the USPS will gain a modest increase of revenues from sales of additional waste paper. Potential export sales to other industrialized countries could be substantial. Clearly, the dominant economic benefit will accrue to users of this mail system through avoidance of expected future rate increases.

Table 1: Summary of Annual Economic Benefits of the E-Mail System.

Sources of Economic Benefits	Jobs	Payrolls ($ millions)	Sales ($ millions)
New Paper Production Wholesale Distribution of Paper Recycling of Scrap Paper	1750-2750 850-1150 275-465 2780-4365	28-43 9-13 2-3 39-59	150-250 150-225 12-20 312-495
Continuation of Employment Communication-Electronics Industry USPS E-Mail Operations	66,000 60,000	660 1200	1,216 2/
USPS Sales of Scrap Paper	1/	1/	7-13
Potential Export Sales	1/	1/	1200-2400
User Savings- Postal Rate Increases Avoided	1/	1/	5,000-7,500

1/ included elsewhere
2/ from the E-Mail system cost analysis

2. Energy

It is most probable that transmitting 50 to 75 billions of pieces of mail per year via satellite will consume considerably less energy than would be used by the present combination of trucks, trains, and aircraft. To date, efforts to quantify these savings have demonstrated that this is an extremely complex problem and have not yet been successful.

3. Environment

At first glance, the increased demand for paper would seem to imply increased cutting of timber. If this occurs, it can only be a nominal increase since the anticipated increase of paper sold by wholesale dealers has been estimated above as only 3 to 4 percent of sales for 1972.

The 300 to 500 tons per year of additional paper used will not contribute to environmental pollution or waste management problems. Waste paper dealers will be anxious to return this paper to the production process through recycling. These quantities will contribute to increasing the total amount and proportion of paper reclaimed even though the increases will not be large relative to current data.

4. Protection of Life and Property

The electronic mail system will provide rapid and reliable delivery of mail. It will enable the Postal Service to reduce the volume of misdirected mail and the consequent duplication of handling. Perhaps it is more important that the property interests of private citizens and businesses will be enhanced by more rapid delivery of the communications content of their letters and will be more fully protected from misdirection or loss. It would be extremely difficult to quantify the property value of more rapid delivery or of reduced losses from misdirection and loss. No such estimate has been undertaken here.

5. Food and Natural Resources

The additional demand for paper has been estimated to have only a nominal impact on the use of timber resources.

6. New Knowledge

This system is not expected to produce new knowledge in basic science or engineering. On the other hand, new sub-systems applications and production techniques can be expected in the communications industry from the production and implementation of the system.

7. Summary

The expected socio-economic benefits of the electronic mail system are summarized in Table 2 which follows.

Table 2: Potential Benefits of an Electronic Mail System

National Need	Potential Benefits
Economy	• new jobs, payrolls and sales in paper production, wholesale distribution, and recycling • support for continued employment, payrolls, and sales in communications-electronics and the USPS • USPS cost savings and increased revenues • potential export sales
Energy	• potential savings
Environment	• nominal increase of timber cutting • expansion of paper recycling
Protection of Life and Property	• reduction of lost or misdirected mail
Food and Natural Resources	• nominal increase of timber cutting
New Knowledge	• sub-systems applications and production techniques in communications-electronics

Relationship to National Needs

The electronic mail system would support each of the National Needs of this study.

Benefits to the Economy would include:

- Additional jobs, payrolls, and sales in the production, distribution and recycling of paper.
- Continuation of jobs, payrolls, and sales in the domestic communications-electronics industry, plus potential export sales.
- Potentially great postal rate savings for mail users with increased revenues and cost savings for the USPS.

Substantial savings of Energy are probable.

The Environment would be enhanced through a stimulus to recycling of paper.

A contribution to the Protection of Life and Property would be achieved by reduction of lost or misdirected mail.

The impact on Food and Natural Resources would involve only a nominal increase of timber usage.

New Knowledge of sub-systems applications and production techniques would be gained.

Relationship to NASA/OAST Space Technology Goals:

The Electronic Mail application will lean heavily on advanced technology projections largely in the information acquisition and management areas. As stated on page 2, these projections will meet the requirements of the system.

Summary and Conclusions

- The technology required for the electronic mail system will be available within a decade. The system could be tested within 5 or 6 years and fully implemented by 1990.
- The need for faster, more reliable, and less costly mail service is pressing.
- For nationwide service, the system will require three geosynchronous satellites, with periodic replacements, and about 25,000 transmitter-receiver stations in Post Offices.

- Development costs will approximate $12 billion during the initial six years. Annual operating costs of $4.62 billions are dominated by personnel costs, most of which will be spent for mail service whether or not this system is developed.

- Substantial socio-economic benefits will accrue to the nation, its industry, and its people.

- The system recommends itself for near-future development and implementation.

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PERSONAL TELEPHONE COMMUNICATIONS

TABLE OF CONTENTS

Application: Personal Communications

Background:

One of the major objectives of the U.S. space program is to provide space systems which are of direct benefit to the average citizen. Many people are now benefitting from communications satellites: telephone conversations with other continents; live television from Hawaii, Europe, and Asia; and expanded and improved educational T.V. Better weather prediction is now possible. However, the average person is probably unaware of the contribution of space systems to his well-being or enjoyment.

Personal communications is a project that will enable each man to utilize space for his own benefit. With a small transmitter-receiver, about the size of a wristwatch, he will be able to talk, via communications satellite, with any person similarly equipped. Since normal telephone communications systems will interface, he will be able to talk to practically everyone -- whether at home, in the office, in an automobile or ship, or on the street.

Improved space technology will make this possible. We will be able to make satellites large and highly capable. The expense of deploying such a satellite, with an antenna about the size of a football field, in geosynchronous orbit will be large -- but will be recovered by the ability to make use of small, portable, and inexpensive mass-produced instruments on Earth.

Communications between individuals is only a small part of the benefits to be derived from such a program. It would benefit mankind in many areas: search and rescue, law enforcement, locating of surface transportation and ocean vessels, and collision warning to name but a few. It could, with proper safeguards, replace or augment our present polling procedures.

The growth of telephone requirements during the next two decades may render such a system a necessity. Even if this is not the case, personal communications; combined with electronic mail, improved weather prediction and crop forecasting, and other benefits to be derived from space activities; would provide the farmer, businessman, legislator, pilot, seaman, and the military, the ability to make instantaneous decisions. All of our lives would be affected for the better.

Objective

A communications satellite, consisting of electronic transmitting-receiving equipment and a large space lens antenna system, will be placed in geosynchronous orbit above the equator west of Quito, Ecuador. Power of about 20 kilowatts will be provided to the system by a large solar panel array.

This will enable two-way voice communication between ground radio sets the size of a wristwatch which would sell for about $10.00 in mass production. The entire system would, through receiving centrals, be tied-in to the normal telephone system. This would yield almost complete voice communications flexibility.

Millions of people would be serviced by such a system. By 1990, twenty-five city areas of about 120 kilometers in diameter will be covered initially, each providing service to a million subscribers. There will also be the facility to reach remote areas not covered by the system. The system would then be enlarged so that the entire U.S. and, indeed, the whole Earth could be covered.

System Description:

1. The Ground System

The ground system will consist of personal transmitter-receivers as well as telephone centrals located in each city area. The personal wristwatch devices are pictured in actual size in Figure 1.

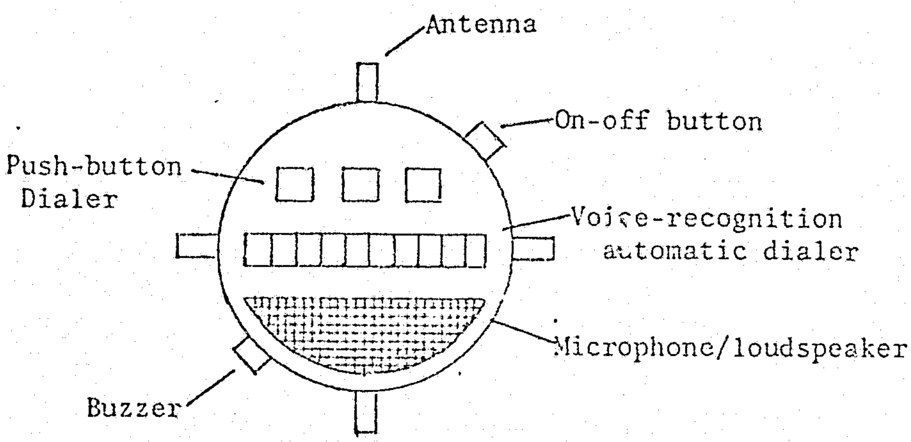

FIGURE 1: PERSONAL COMMUNICATION SYSTEM

A call can be placed either by push-button dialing or a voice recognition automatic dialer. The buzzer will signal an incoming call. The antenna system may be isotropic (omni-directional) or, as seen in the Technical Discussion; upper-hemisphere propagation may be required.

The characteristics are as follows:

- weight: about one ounce
- power: 0.025 - .5 watts
- battery life: 20 hours
- cost: about $10.00

The cost of approximately $10.00 is quite realistic. The electronics in the radio are practically present state-of-the-art. The system will be no more complicated than present-day portable calculators, battery-operated radios, or walkie-talkie devices. It would not have to accommodate a wide range of frequencies.

The cost of the telephone central systems would be minimal. Sixty-centimeter antennas, with standard switching equipment are needed.

2. The Space System

A large communications satellite will be deployed in synchronous equatorial orbit; at an altitude of 35,200 kilometers west of Quito, Ecuador. From this location the entire continental U.S. is visible to the satellite.

The satellite system is depicted in Figure 2.

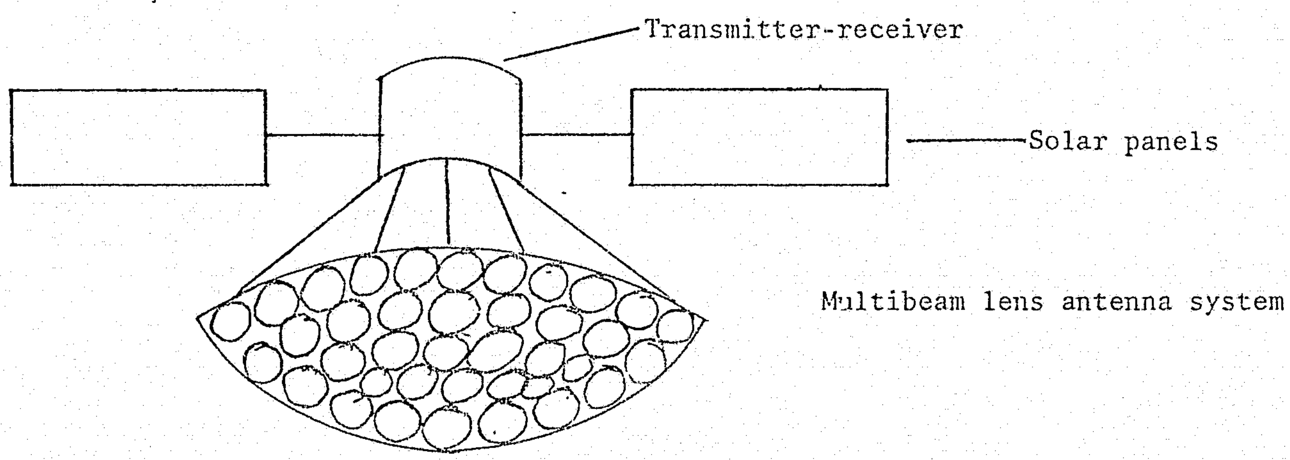

FIGURE 2: COMMUNICATIONS SATELLITE SYSTEM

This satellite will consist of: (1) the electronics subsystem for receiving, transmitting, amplification, and switching; (2) solar cell arrays for power generation; and (3) an array of thirty multibeam antennas. The satellite will relay signals between any two wrist radios or between wrist radios and the telephone networks.

The transmitter-receiver assembly will accept signals from any of the thirty parabolic lens antennas. It will select the proper channel for retransmission, amplify the signal and retransmit.

The solar panels will generate the power required to operate the total system. It will require about 21 kilowatts of pure power with 7 kilowatts for transmitting.

The antenna subsystem will be about 300 feet in diameter. It will consist of thirty lens antennas, twenty-five aimed at the centers of 120 kilometer diameter zones. The other five antennas will be steerable. In this way they can be focused on any location in the continental U.S. or nearby water as commanded from the ground. These would be used for search and rescue, law enforcement, and location of surface and ship transportation.

A summary of the space system follows:

- weight: 9000-12,000 pounds
- size: 150-300 feet in diameter (antenna)
- raw power: 21 kilowatts
- lifetime: 10 years with yearly servicing
- cost: $400 - 600 M.
- availability: 1990.

The system would provide the following capability:

- 25 fixed beams
- 5 steerable beams
- 7 kilowatts power, S-band
- 1,000 channels/beam
- 1,000 users/channel

Therefore, one million people in each of twenty-five cities and environs can communicate, 25,000 simultaneously, using ordinary voice. The capability is also provided to communicate with any location in the continental U.S. or nearby ocean areas as required.

3. Deployment

The large antenna array will be assembled in low earth orbit. This will probably require about six shuttle flights over a six-month period. The antenna system will then be mated to the electronics subsystem and the solar array. The space tug will then carry the entire system to geosynchoronous orbit, where it will be checked out, repaired if necessary, and placed in operation. The total activity would take about one year and require about eight shuttle flights and one space tug mission.

A maximum of one shuttle flight per year will be required for servicing and possible modifications.

Technical Assessment:

1. Range Equations

For purposes of this discussion we shall use the following range equation: 1/

1/ Jaffe, Leonard, Communications in Space; Holt, Rinehart, and Winston, 1966 - pp. 27-32

(1) $$P_R = \frac{P_T G_T G_R \lambda^2}{16 \pi^2 D^2 L}$$

where P_R and P_T are the received and transmitted power, respectively; G_R and G_T are the receiving and transmitting antenna gains; λ is the wavelength; D the maximum distance; and L is the system losses.

P_N, the self-produced noise power of the receiving station is

(2) $$P_N = KTB$$

where K is Boltzmann's constant ($K = 1.38 \times 10^{-23}$ watts/degree K/sec.), T is the system noise temperature; and B is the RF bandwidth given by

(3) $$B = 2 F_p (M + 1).$$

F_p is the peak frequency (4 kH_z for voice) and M is the modulation index.

The signal-to-noise ratio is then given by

(4) $$\frac{S}{N} = \frac{P_R}{P_N} 3M^2$$

$3M^2$ is the FM improvement factor.

2. Range Calculations

In most communications satellite system, the downlink is the limiting case, since we can essentially put as large an antenna as we require on the ground. However, in the personal communication system, the uplink will be most critical.

Discussions of the personal communications systems have assumed the following characteristics:

- The wristwatch radio will have 0.025 watts of power and its antenna is isotropic (omni-dimensional).
- The satellite system has 7 kilowatts of transmitting power and its antenna system consists of twenty-five 30 ft. diameter parabolic lenses.

Our calculations show that this may not be enough.

In logarithmic form, the above equations become:

(5) $P_R(dbW) = P_T(dbW) + G_T(db) + \lambda^2(db) - 16\pi^2(db) - D^2(db) - L(db).$

(6) $P_N(dbW) = K(dbW) + T(db) + B(db)$

(7) $\frac{S}{N}(db) = P_R(dbW) - P_N(dbW) + 3M^2(db)$

Using the above characteristics we have, for the uplink, $P_T = 0.025$ watts and $G_T = 0db$. For one 30 ft. parabolic lens, the gain is $G_T = 55db$, i.e. $6.2A/\lambda^2$. We shall select a maximum distance of 40,000 kilometers and a wavelength of 0.123 ft. corresponding to 8GHz. Then

$P_T = 0.025$ watts	$P_T = -16dbW$
$G_T = 1$	$G_T = 0db$
$G_R = 55db$	$G_R = 55db$
$\lambda = 0.123$ ft.	$\lambda^2 = -18db$
$D = 13.123x10^7$ ft.	$D^2 = 162db$
$L = 5$ db	$L = 5db$
	$16\pi^2 = 22db$

and, from (1) we have

$P_R = -168dbW = 5X10^{-17}$ watts.

With a peak frequency of 4kHz and a modulation index of 3, we have an RF bandwidth of 32kHz. Assuming a system noise temperature of 200°K at the receiver, we have

$K = 1.38x10^{23}$	$K = -229db$
$T = 200$%K	$T = 23db$
$B = 32kHz$	$B = 45db$

This yields $P_N = -161dbW$ and our signal-to-noise ratio is

$\frac{S}{N} = 7db$

Ordinarily, an acceptable signal-to-noise ratio should be about 30db for useful audio. We see that 7 db is not acceptable.

For the downlink, using $P_T = 230$ watts, $G_T = 0db$, and $T = 1000°K$, we have a signal-to-noise ratio of 41db which is in the acceptable range.

3. Systems Modifications

A variety of modifications could be used to improve the performance.

- Increasing the power of the wrist transmitter from 0.025 watts to 0.5 watts would give an improvement of 13db.
- Modifying the omni-directional characteristics of the wrist antenna to propagate in the upper hemisphere would give an improvement of 3db.
- Doubling the diameter of the satellite antenna to 60 ft., increasing the gain to 61db, would give an improvement of 6db.

These three modifications would then yield a signal-to-noise ratio of 29db which would be satisfactory.

There are probably other modifications such as an improvement in the modulation index that would help. If the size of each antenna can be held down, the cost of the system, deployed in geosynchronous orbit, would be much less. In any event, the originally described system would probably not be adequate.

Operational Use of the System:

A schematic of the personal telephone system is included as Figure 3.

1. Normal Operational Modes

There would be four normal operational modes of communication between the personal telephone (PT) and the telephone centrals (TC).

Mode A: PT to PT

Both parties are subscribers to the personal telephone system, are located in a serviced area, and are accessible to the system at the time of the call. This would be the usual mode and the least costly. Also, the costs would be the same irrespective of the locations of the two parties.

Mode B: PT to TC

The person at the receiving end is: (1) not a subscriber but is in a serviced area, (2) is a subscriber in a serviced area but not available by PT at the time of the call, or (3) is not located in a serviced area. The cost to the sender would be the same as Mode A, but the costs of the telephone service would be added to in the costs of the receiving party.

Mode C: TC to PT

The reverse of Mode B. In this case, the costs to the originator would be at a premium.

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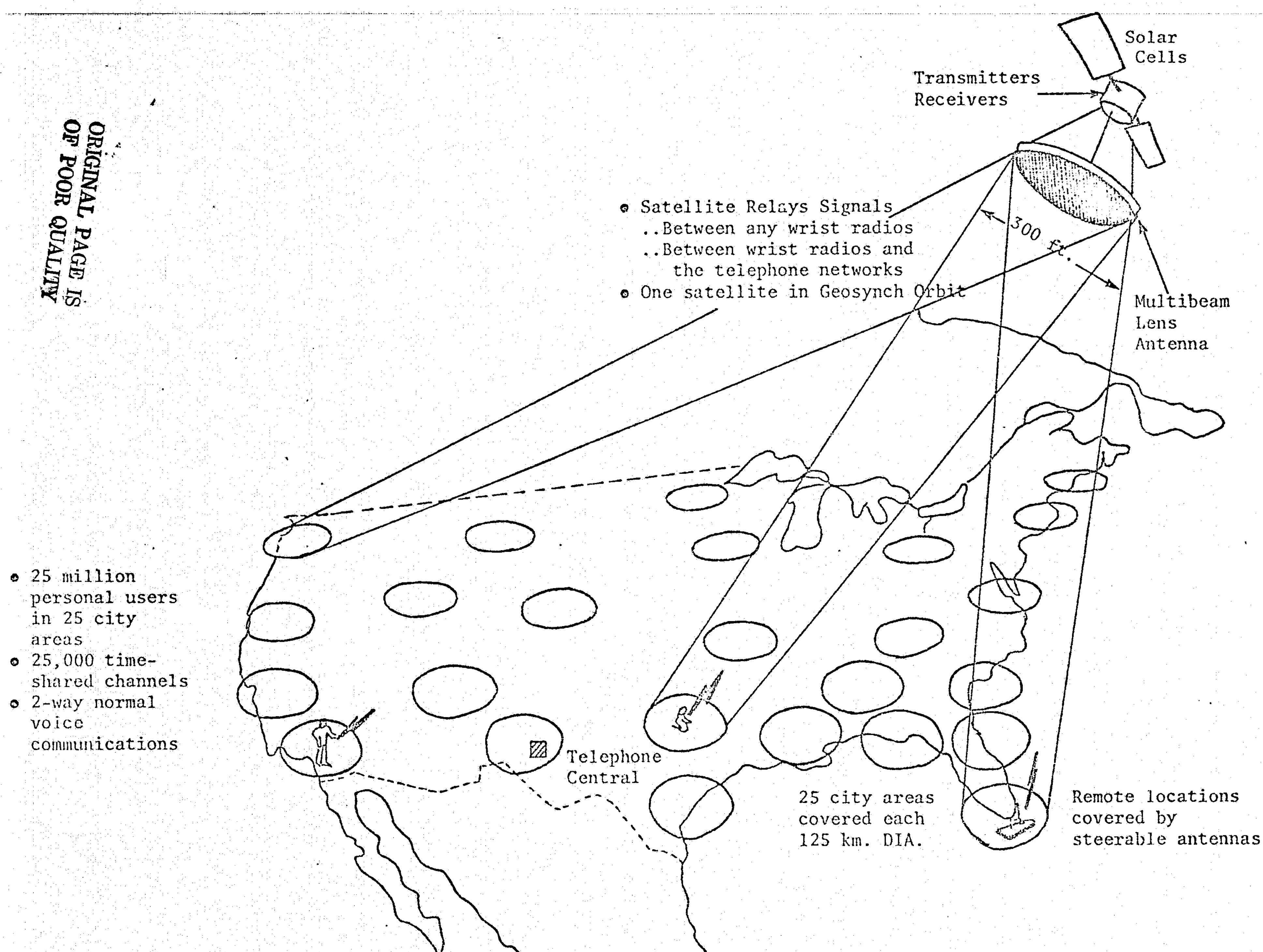

FIGURE 3. PERSONAL COMMUNICATIONS SYSTEM

Mode D: TC to TC

Neither party is available by personal telephone. This would result in a premium at both ends. However, in this mode the communications satellite need not be used.

2. Possible Billing Systems

These modes may or may not require a billing system. There are a variety of options. Three of these are:

Option A: Subscription

The user subscribes to the system by deposit and pays a flat monthly rate to the provider of the service. He can rent or purchase the wristwatch device from the provider or retail outlets.

Option B: Subscription plus Billing

The user pays a flat monthly rate but is also billed at a premium whenever his call is anything but normal.

Option C: Billing

The user is billed only when he uses the system. However, he must still subscribe and purchase the wristwatch radio.

The billing under the latter two options can be done by information sent via satellite to a computer system at each involved telephone terminal. However, requiring the satellite itself to time calls or provide any accounting functions would probably not be feasible.

3. Operational Modes Using Remote Personal Telephones (RPT)

There are a number of such operational modes: PT to RPT, TC to RPT, RPT to PT, RPT to TC, and RPT to RPT. Each of these modes would involve steering one or more antennas to propagate into remote areas (those not covered in the regular system). The costs would be prohibitive for personal use. These modes would be used in

- search and rescue
- law enforcement
- ship and surface locators
- defense activities

The agencies would be provided codes to be used in activating the system. Methods of payment would be worked out between the provider of the service and the agencies.

Program Description and Costs

It appears that a program to provide a personal telephone communications by 1990 for the use of private citizens that can also be used for various governmental needs would be feasible. A socio-economic study shows it to be of sufficient benefit to initiate the first phase of the program.

The program would probably take place as follows:

- program definition and study phase
- hardware implementation of the experimental system
- conduct of the experimental system
- hardware implementation of the operational system
- launch, assembly, and deployment of the operational system
- system operations

1. Program Definition and Study and Experimental Phase

This phase would consist of studies and experiments related to: (1) the characteristics and availablilty of required large-scale antenna arrays, (2) the assembly of large structures in low-earth orbit with subsequent transfer to geosynchronous orbit, including the number and frequency of launches required to achieve the objective, (3) the characteristics and availability of small-scale wristwatch devices, and (4) further study of the economic aspects of the system. It would also include the development of hardware for the experimental system. The program definition phase should start within six months. The study phase could start in about one year. The approximate costs would be as follows:

- $1M for program definition (approximately six months)

- $5M per year for two years for technical and operational studies

- $1M per year for two years for economic studies

- $20M per year for four years for definition and production of hardware for the experimental system

This would lead to a launch of the experimental system in six years. This phase would cost less than $100M.

2. Experimental System Phase

This includes launching of the experimental system, probably connecting two or three cities. Hopefully, it could be included as part of an otherwise-planned geosynchronous satellite. The experimental phase would last for about two years, gathering data and assessing results.

Enough data should be established through the first year to enable proceeding with operational system hardware.

The costs associated with this phase are:

- $40M for launch and deployment
- $10M for 2 year technical studies.

3. Operational System Phase

This includes implementation of the operational system hardware, launch and assembly in LEO by the space shuttle, and lifting to synchronous orbit by the space tug. It consists of one satellite with a ten year lifetime and visits every two years.

Very gross estimates for this phase follow:

- $150M: satellite hardware
- $150M: launch and assembly operations
- $10M per year for ten years for operations

4. Total Costs

The total costs from 1977-2000 are as follows:

Phase 1:	$100M
Phase 2:	$ 60M
Phase 3:	$400M
Costs:	$560M

These costs do not inlcude those associated with the ground operating systems.

Socio-Economic Benefits

Impressive social benefits may be expected in time saving, consumer convenience and safety, improved police work and higher employment levels in an expanding communications industry. A reduction in telephone and telegraph plant detracting from the environment and cost savings to the national defense effort are also foreseen.

1. Economy

The wrist radio system's potentially greatest benefits are immense consumer savings, personal safety and convenience. The economic saving results from lower rates. Based on a conservative estimate, a 10 cent reduction from the average toll call will realize an annual saving to consumers of about a quarter of a million dollars.

The savings depend upon both technical and economic considerations. The cost of transmitting long distance telephone calls depends upon the length of the call and the geographic distance between callers. As the distance between the callers increases, so does the amount of transmission equipment required. Wrist radio calls always require the same amount of equipment; the satellite and the two wrist radios. Its transmission cost will depend only on the duration of the call.

The wrist radio would render person-to-person telephone calls and their premium toll charges unnecessary. Unless the user dials a wrong number or the recipient is not wearing his wrist radio, a completed call will be answered by the party sought. The user will have no incentive to pay a higher toll for the guarantee of reaching his party. In 1975, 1.28 billion operator-assisted calls were made, of which a large proportion are understood to be person-to-person calls. The surcharge for a three minute person-to-person call is at least 273% of the toll charge for a direct dialed call and the potential user savings should be considerable.

In 1975 the telephone industry owned 84.6 billion dollars worth of "Plant".1/ The wrist radio calls would require only 30 to 80 percent of this equipment.

From 1971 to 1975 the industry expended an average of 1.9 billion dollars on telephone plant linking telephones and telephone exchanges. The wrist radio would require none of this plant within the 25 metropolitan service areas. The satellite, which costs about half a billion dollars and lasts an estimated ten years, depreciates about 50 million dollars a year.

The savings suggested here could possibly be accompanied by a loss of revenues to the telephone industry from long distance telephone calls. It is likely, however, that the telephone industry would supply service to a portion of the wrist radio system which might well compensate the telephone industry for any losses from reduced toll call usage.

1/ The figures reported in this section refer to the operating companies controlled by the American Telephone and Telegraph Company which account for almost 90% of the domestic telephone business. 1975 Statistical Report, AT&T, New Brunswick, New Jersey.

The wrist radio will not provide all long distance telephone service. As proposed, the system will serve twenty-five metropolitan areas. Calls to other areas will require a link with the telephone system of a nearby metropolitan area that has wrist radio service. 118 million telephones were in service in 1975, almost five times the number of wrist radios expected to enter service. The wrist radio's role would be an alternative service to a limited number of users, not as a replacement for the telephone.

The assumed savings would only reduce toll call revenues to the telephone industry by a maximum of two percent. Since the telephone industry is regulated as a natural monopoly, a "fair" return on their investment is assured.

The predicted demand for this product according to the subject literature would be satisfied in five years. However, enthusiastic consumer response would encourage expansion of the system with accompanying maintenance of sales revenue and employment. Also, replacements and repair of wrist radios should reach significant proportions for those wrist radios which were manufactured during the initial period of the systems commercial availability.

The wrist radio system may have effects on employment in the telephone industry. Its independence from much of the hardware of the conventional telephone system may render unnecessary some portion of future expansion or replacement of equipment in the 25 service areas. This may have marginal effects on industry manufacturing, servicing, and employment. If such a reduction of employment is observable, it probably will approximate the small (2%) decline in industry operating revenues.

New employment will be generated in other sectors of the economy. The two most likely industry groups to benefit are those that will manufacture the wrist radios and those who will produce, launch, and assemble the satellite hardware.

The wrist radio will generate employment and sales revenue for those firms that become engaged in its manufacture. For this analysis, it is assumed that the industry group which is primarily engaged in the manufacture of "Microwave and Mobile Telephone Communications Equipment" would manufacture the wrist radios.[1/] Twenty-five million wrist radios might be sold by the manufacturers for $10.00 each during a five year span. This suggests approximate sales of 50 million dollars per year. Analysis of Census data shows that 50 million dollars a year of manufacturers sales implies an increase of approximately 1,120 employees, with average earnings of $13,000 per year.

A similar analysis indicates an estimated 150 million dollars in sales to be generated in the aerospace industry by the development, manufacture, and deployment of the satellite. This expenditure is expected to add approximately $62 million to the payrolls in these firms. This represents approximately 3,300 jobs at $17,000 per year.

1/ Census of Manufacturers, U.S. Bureau of the Census, MC 72(2)-3600. 1972, p. 36D-26.

Specialized groups often have unique communications needs. Such groups will obtain greater efficiency and lower costs by using the wrist radio in a standard or custom model. For example, well-equipped police departments supply each patrol officer or group with a communications unit. These may be mobile radios in patrol cars and cycles or the "handy-talky" for foot patrolmen. These radios range in price from $500 to $1500 each. A conservative estimate for 1974 indicated that there were almost 125,000 communications units in use by state and local policemen.1/ We estimate that fire departments would use about half that number. A custom model of the wrist radio, with special capabilities for police and fire department needs, could be produced for $100, only 10 times the expected price of the consumer model. This implies an average savings of $700 for each of about 185,000 units, or public service savings of approximately $130 million. These savings would be realized gradually as police and fire departments replace obsolete equipment.

Another law enforcement benefit will become available to wrist radio users. This user, either as victim or observer of a crime, will be able to report it much sooner than if forced to find and use a telephone. This benefit is illustrated by a study of travel times in an urban area to predict the probability of detecting a criminal as a function of "time late".2/ If time late can be reduced from 6 to 4 minutes (the Washington, D.C. Police Department claims an average response time of 3 minutes) with the wrist radio's immediate reporting capability, the probability of detecting a fleeing suspect would increase from 36% to 50%. Based on a national estimate of total unrecovered property stolen by burglars, the increased effectiveness (from reduced time late) would result in more than $86 million of this property being recovered. Without doubt, decreases of time late will aid in controlling other types of crime.

Similar benefits will arise from greater speed in reporting fires. For example, the least severe type of major fire will reach a temperature of 500° to 700°F in 10 minutes. 3/ But, after only 5 minutes, the temperature will be in the range of 300° to 500°F. This illustrates the dramatic impact of timely reporting on the effectiveness of efforts to control and reduce damages.

Search and rescue operations will be enhanced by availability of the wrist radio. Rapid and totally portable communications capability will facilitate coordination among searchers. When the subject of the activity has a wrist radio, prompt recovery will become a routine result. Search and rescue expeditions usually require two days of effort for many people and often involve helicopters and other expensive equipment. The wrist radio offers the potential for substantial reductions of effort, costs, time and suffering.

1/ Statistical Abstract of the United States, 1975, U.S. Department of Commerce, Bureau of the Census, July 1975.

2/ "Time late" is the interval between the occurrence of a crime and the arrival of the police on the scene. Bottoms, Albert M., Police Tactics Against Robbery, National Institute on Law Enforcement and Criminal Justice, August 1971, pp. 84-86.

3/ McKinnon, Gordon P. (Ed.) Fire Protection Handbook, National Protection Association, Boston, 14th Edition, pp. 6-80 through 6-83.

To summarize, the personal communications capabilities of the wrist radio will generate large and diverse economic benefits. It has been possible to estimate the probable magnitudes of some benefits and to describe others. The quantifiable annual benefits of the wrist radio system are presented in Table 1.

TABLE 1: ESTIMATED ANNUAL ECONOMIC BENEFITS - WRIST RADIO SYSTEM

Savings:			
• reduction of 10¢ per long distance call for 25 million users			$225 millions
• reduced cost of mobile radio equipment for Police and Fire Departments			$130 millions
Industry gains:	Jobs	Payrolls	Sales
• Communications electronics	1120	$15 millions	$ 50 millions
• Aerospace	3300	$62 millions	$150 millions
Recovery of Stolen Property:			$ 86 millions
		Total	$641 millions

Savings to individual users and public service agencies will surely exceed the $355 millions per year as indicated here. At the least, there are other agencies who can make similar use of this system. Industry sales should increase by $200 millions annually for several years. The economic value of this communication systems' contribution to crime suppression obviously is underestimated by the $86 millions per year from recovery of stolen property. It is clear the sum of $641 millions per year of savings, sales, and recovered property is a low estimate of the potential economic benefits of the wrist radio system.

2. Energy

No significant benefits are anticipated.

3. Environment

No significant benefits to the environment are expected in the near future. The wrist radio system will attract some current use and absorb some growth from inter- and intracity telephone usage. This will diminish the need for telephone poles and cables. A gradual reduction of exposed cable networks will contribute to reduced clutter and improved appearance of the cities.

4. Protection of Life and Property

A wrist radio system will help to save lives, protect personal property, and increase military effectiveness.

In 1975, 1.8 million people were injured in automobile accidents in the U.S. and 45,600 were killed.1/ A survivor or observer of an accident could summon the police and an ambulance much more quickly with a wrist radio than with the telephone. Estimates of reduced death and injury effects -- from more timely arrival of police and medical health -- are quite variable. Nevertheless, it is obvious that the immediate communication capability can only be beneficial. Similar benefits would pertain to other medical emergencies.

The effectiveness of search and rescue efforts will be enhanced greatly. When every searcher can have a totally portable radio set, coordination will be improved greatly. If the lost party had a wrist radio, a prompt rescue could become routine. The risk of exposure or starvation would become minimal.

The wrist radio can help the police to protect lives and property. It has been reported that the probability of detection is increased by reducing the "time late" interval. 2/ The ability of a victim or observer to contact the police instantly would help the police to respond more quickly. This would aid in detection and apprehension of criminals. The increased risk of apprehension would deter some criminals and reduce crime rates.

Fire protection would be improved. There are obvious benefits from reducing the time interval between ignition of a fire and reporting it. Decreasing the "time late" also increases the chances of alerting and removing to safety persons unaware of the fire or trapped in the vicinity. Further, a wrist radio user could direct firemen at the scene to his secluded or trapped location, facilitating rescue.

1/ Data obtained by phone from the American Automobile Association.

2/ Bottoms, Albert M., *op. cit.*

The military services would find many uses for the wrist radio to increase their effectiveness. The advantages of flexible, totally portable, and instant communications are of great value to tactical forces.

5. Food and Natural Resources

No immediate effects are anticipated. After some years, some conservation of natural resources would occur through eliminating the necessity of replacing long-lines equipment. Minor savings of timber would result from a decreased need for telephone poles. The complimentary savings of copper and other scarce minerals for other uses may be much more important.

6. New Knowledge

Development and implementation of the wrist radio system will add new dimensions of space technology. The system will require a space shuttle system and the capability of assembling complex structures in space. Beyond gaining the "know how", the shuttle system and space assembly yard will be available for other programs and will be the forerunners of others to follows.

Relationship to National Needs

The wrist radio communications system would support most of the National Needs of this study.

Economic benefits would include:

- Savings to consumers both from lower rates and the avoidance of toll call premium charges.
- Sales income, and employment in the aerospace and communications-electronic industries.
- Lower communications equipment costs for departments, search and rescue teams and the military services.
- Reduced losses of life and property through reducing the response time of police and fire departments.

Environmental benefits may be realized through the elimination of some open air telephone transmission equipment.

Improved Protection of Life and Property through increased effectiveness of police and fire department efforts, search and rescue operations, and emergency medical assistance.

Natural Resource conservation will be increased as a result of decreased demand for scarce metals used in telephone plant.

New Knowledge will be gained through advancing space related technical capabilities.

Relationship to NASA/OAST Space Technology Goals:

This application will require the achievement of many of the space technology goals.

First and foremost, it will require a very large space structure. The antenna configuration itself will be about 300 feet in diameter.

It will require the assembly of this large structure (about 10,000 pounds) in low earth order with a subsequent transfer to geosynchronous orbit.

The requirement for 21 kilowatts of raw power will require a very large solar array in geosynchronous orbit. An energy storage system may be required.

The total space system, particularly the antenna system, will be highly complex. The development of a highly-capable adaptive array with as light-weight a structure as possible will be a difficult design problem.

Summary and Conclusions

- A personal communications system, using geosynchronous satellites with large antennae and small personal transceivers, is feasible with expected technological advances.

- It will require communications satellites of uncommon size, requiring a space shuttle system and capability for assembly in space.

- System development and experimental phases would cost about $160 million. Implementation costs will approximate $300 millions and, annual operations costs of $10 million are estimated. The program could begin by 1983 and be operational by 1990.

- The personal communication system will produce substantial social and economic benefits, expected to surpass $640 millions per year.

WEATHER AND CLIMATE MONITORING, PREDICTION AND CONTROL

TABLE OF CONTENTS

Application: Weather and Climate Monitoring, Prediction, and Control

Background:

1. Influences on the Earth's Weather

The influences on the Earth's weather are well known. They are: (1) the action of the Sun as a nuclear furnace, (2) the geometry of the Earth, (3) the Earth's atmospheric blanket, and (4) the geophysical landform of the Earth.

The Sun's nuclear processes emit radiation in all directions in the form of ultra-violet rays, infrared rays, and visible light. Of the small amount that reaches the Earth's vicinity some is scattered by air, dust, and water vapor; some is turned back by clouds; and the balance is absorbed and converted into heat. This heat evaporates the water in the oceans and warms the lower atmosphere. The resulting circulation gives rise to winds, cyclones, hurricanes, storms, and precipitation.

The Earth's spherical shape affects the intensity of radiation received from the Sun at various latitudes. The Earth's revolution about the Sun and its tilted axis again modify the amounts of radiation received and cause the seasonal changes. The Earth's rotation about its axis along with heat effects give rise to the wind flow patterns.

The troposphere (5-10 miles above the surface) is a layer of heavy air; its weight is about 80% of that of the entire atmosphere. It contains all of the water vapor. In the troposphere, the circulation of the atmosphere takes place - generally rising air at the equator sinking earthward at the poles. In the Northern Hemisphere, this south-north circulation, modified by the west-east flow caused by the Earth's rotation, results in the trade wind patterns.

The Earth's geophysical landform also has a profound effect on the weather. The oceans, continents, islands, and lakes, since land gains and loses heat more quickly than water, affect the heat profile. Mountainous areas and valleys cause updrafts and downdrafts which affect the local circulation flow.

2. Numerical Weather Prediction

Meteorology has been characterized as one of the most complex of the physical sciences. John Von Neumann stated in 1956:

> "The hydrodynamics of meteorology presents without doubt the most complex series of interrelated problems, not only that we know of, but can imagine."

In spite of this, great strides have been made in dynamic meteorology and numerical weather prediction. With the additional knowledge to be provided by future space activities a tremendous further breakthrough is about to occur.

Numerical weather prediction can be thought of starting as a consequence of Isaac Newton's second law of motion, the Concept of Predictability 1/: the rate of change of the momentum of a parcel of matter is equal to the sum of the forces that act on the parcel, that is;

$$\frac{dM}{dt} = \text{sum of the forces}$$

Since, at any initial time to, the quantity on the right exists, the initial values can be measured, and from:

$$dM = (\text{sum of the forces})\ dt$$

a nearby future value can be calculated. This is an example of an initial-value problem in classical physics.

However, let us consider a parcel of air, which consists of water vapor, other gases, and electrically charged ions. Its pressure, temperature, and density can be measured at any point in time. These characteristics are constantly changing. Also they interact, a change in one produces a change in the others. The parcel also moves as a mass in swirls and collides, intermingles, and interacts with other air parcels. Add the effects of the Earth's rotation, clashing warm and hot air masses, turbulences, and thermal influences and our problem of predictability becomes -- although it exists theoretically, to what degree does it exist in weather prediction.

Recognizing that the problem of weather prediction was a classical initial-value problem, V. Bjerknes 2/ and his collaborators, in 1904, set out to build a theoretical model for weather prediction. A network would gather regular readings of temperature, pressure, humidity and wind velocity at the Earth's surface and in the upper air. These data would constitute the initial state of the atmosphere. Then the data would be used, with equations developed in the new field of dynamic meteorology, to compute the weather to come. However, they were unable to find suitable numerical methods to solve the complex formulas.

L. F. Richardson 3/ determined to solve these equations by expressing them in terms of the elementary arithmetic functions. He completed and published this work in 1922. However, even if given enough suitable data, the numerical processing would have required 64,000 mathematicians, equipped with a like number of calculators, working 24 hours a day each day of the year.

Von Neumann and his associates, a group of mathematicians and meteorologists, further refined these mathematical formulations and, by 1956, were performing analysis and weather prediction using the methods of dynamic meteorology and the high-speed electronic computer.

1/ Sverre Petterssen, Introduction to Meteorology, 3rd Edition, McGraw-Hill, 1969 - pg. 21-23

2/ Weather, Life Science Library, Time-Life Books, 1973 - pg. 135-137

3/ Ibid - p. 137

With the subsequent increase in observation stations, upper-air sounding stations, radar surveillance stations, and weather satellites, accurate short-term weather prediction is a reality. However, it has been estimated that if accurate prediction can be made as much as five days in advance, the savings in the U.S. alone in the management of water resources and lower costs in many areas (agriculture, transportation, retail marketing, lumbering, etc.) could be in the billions of dollars. The improvements that are needed to improve the accuracy and widen the validity (first up to five days and ultimately to an achievable ten-twenty days) of weather prediction are:

- more refined mathematical formulations
- more extensive, accurate, and timely data collection
- expanded data-processing capabilities

3. Climate Prediction

Accurate weather prediction for periods of a few days to about a month will aid in countless ways. Ultimately, an understanding of the internal and external conditions that affect climate would enable us to predict climate on a seasonal or even yearly basis. Since the evidence indicates that the Earth's climate fluctuates over decades, centuries, and even longer time periods, an in-depth knowledge of climate could have advantages to mankind beyond measure.

A potential Climate Program has been discussed in some detail in The Outlook for Space, pages 152-161. This need not be repeated here. The following outlines the approach to the understanding and prediction of climate in four areas: data base, environmental monitoring, model development and forecasting, and assessment of man-made effects.

- Data base: Develop a body of information on climate and its variation with enough statistical accuracy to distinguish actual climatic trends due to real climate changes from normal weather fluctuations. This entails the use of instrumental records, historical records, and paleoclimatic records.

- Monitoring: Identify and monitor the factors that control and/or influence the climate, determine the potential for change in each, and determine the climate's probable response to such changes. Satellites would be a basic part of the observing system.

- Forecasting: Determine the predictability of climate on various time scales and, to the extent possible, develop a forecasting capability. This would involve extensive mathematical modeling of the climate system.

- Human effects: Identify and monitor activities of humans which may change the climate; and assess their actual impact on the climate; investigate possible measures to counteract adverse changes or bring about desirable changes.

An overall program for climate prediction will be a long-term effort. Data will have to be collected over many decades. The program will involve a wide-variety of ground-based activities. However, certain data gathering, long term and global in nature, will require refined satellite systems. Satellites with some other primary function may be used for much of this activity.

4. Weather Modification

Possible desirable areas of weather modification include: control of rainfall, reduction of the intensity of severe storms, frost control, and smog abatement. Many benefits would occur from such programs. However, any such activities would have to be subjected to extensive analysis and carefully-controlled tests.

NASA will be able to support these tests by the use of satellite monitoring to measure conditions prior to, during, and after the experimental activities.

Objectives:

John F. Kennedy, the late President of the U.S., in a speech to the U.N. early in 1961, emphasized the need for cooperative efforts between all nations in weather prediction and eventually weather control. In December of that year, the General Assembly unanimously adopted a resolution embodying his proposal which called upon member states to take steps to advance the state of the atmospheric sciences and to develop meteorological services, with worldwide benefits to mankind. The objectives of the research to be associated with the World Weather Watch were stated:

- To develop a deeper understanding of the global circulations of the atmosphere and the associated system of climates.
- To place weather forecasting on a firmer scientific basis: to develop techniques for predictions on extended time scales and to provide knowledge needed to improve weather forecasts of small space scales and time spans.
- To explore the extent to which weather and climate may be modified through artificial means.

To meet these objectives, the international scientific community has recently organized the Global Atmospheric Research Program (GARP) and is now planning the details of that program, the First GARP Global Experiment (FGGE).

The objectives of NASA in supporting these programs are:

- To provide improved communications through the use of larger, more reliable communications satellites, with on-board data handling capability.
- To furnish weather satellites, in low-earth and synchronous orbits, with highly sophisticated data gathering and information handling capabilities in the areas of: improved and newly developed sensor systems, control systems providing better pointing accuracy, and high-speed, reliable data-handling systems with large-scale, rapid-access memories.

Program Summary

1. Weather Prediction System

The Global Atmospheric Research Program is described in Outlook for Space, pages 60-62 and is included here for reference purposes:

"In order to improve the accuracy and extend the useful range of large scale weather forecasting, the international scientific community has organized the Global Atmospheric Research Program (GARP) and is now planning the details of the major activity of that program, the First GARP Global Experiment (FGGE). The basic elements of the global experiment are an observing system and a data processing system. The observational phase of the experiment, to commence in late 1978, involves the measurement of the large-scale state and motion of the entire atmosphere over a period of approximately one year. The data processing aspects of the experiment involve the conversion of instrument readings to useful meteorological variables and the use of these data in numerical models of the general atmospheric circulation for long-range, large-scale weather forecasting. The goal is to improve forecasting accuracy and an extended useful range of forecasting from the present three days toward the ultimate limit of predictability, estimated to be between 10 and 20 days.

The success of FGGE is predicated upon obtaining global observations of the state of the atmosphere at least once every 12 hours. The primary platforms for these observations are two to four Sun-synchronous polar-orbiting satellites with instruments for measuring atmospheric temperature and humidity and sea surface temperatures, and five geosynchronous satellites returning visible and infrared images for deriving winds, cloud amounts, and cloud heights. Winds and boundary layer parameters are also obtained by satellite tracking and collection of data from free-floating balloons, ocean buoys, and remote monitoring stations.

Global observations are essential to these goals; and spacecraft provide the only practical method for such observations. In addition to its direct benefits, improved forecasting of large general atmospheric circulation also provides the basis for local weather forecasts, including forecasts of mesoscale phenomena such as severe storms. The forecasting of these localized, near-time phenomena will be a focus of the 1980s. The understanding of the large general atmosphere circulation will also play a role in weather modification and climate programs. Research and operational meteorological programs contribute to both requirements and the necessity of international cooperation because of the dynamic, global nature of the atmosphere.

In order to pursue this objective, a continuing research and development program leading to improved operational systems would be required.

By 1985 an operational system based upon the results of the GARP global experiment could be implemented. The network would include two to four satellites in near-Earth Sun-synchronous orbit. It would also include satellites in geostationary orbit which serve the dual purpose of supporting large-scale weather forecasting, and severe storm and local forecasting. Measurements of sea and air temperature and humidity would be obtained every 12 hours for a horizontal scale of 100 km. Winds would be measured on a horizontal scale of 200 km by tracking clouds with images from geosynchronous satellites and by tracking free-floating balloons. Polar and sea ice would be measured every five days at a scale of 30 km. In the mid-1980s an experimental system to measure with doppler radar could be deployed.

In the early 1990s, an improved system, consisting of four satellites in near-Earth Sun-synchronous polar orbit and three three-axis stabilized geosynchronous platforms, could be operational. Measurements would be made on a horizontal scale of 50 kilometers (10 kilometers for ice). Active near-infrared sensors would be used for temperature and humidity profiles and wind measurements would be obtained with a multifrequency doppler system."

A summary of the spacecraft requirements follows:

Experimental System (1978-1985)

- 2-4 Sun-synchronous polar orbiting satellites

Operational System (1985-1990)

- 2-4 near-Earth Sun-synchronous satellites
- 2-3 equatorial geosynchronous satellites

Improved Operational System (1990)

- 4 near-Earth Sun-synchronous satellites
- 3 three-axis stabilized geosynchronous platforms

2. Climate Prediction System

The ground systems would support a variety of activities such as:

- gathering of historical data -- instrumental and documentary data
- gathering of observational data from satellites and ground-based facilities
- data processing systems for formulation and modeling
- data processing for climate prediction

Communications facilities, either ground or satellite systems, would be required to furnish the data to the processing facilities in a usable form.

The monitoring system would, in addition to ground weather stations, consist of observation satellites, weather ballons, and unmanned sensors in remote locations. Data from these sensors would be relayed through satellites to the appropriate ground-based facilities.

Much of the weather prediction system could be used. Certain new sensors, particularly for the monitoring of conditions external to the atmosphere, would be required.

3. Weather Modificiation Experiments

Satellite systems deployed for weather prediction activities could also carry instruments and data processing equipment for monitoring weather modification experiments. By 1985, a high-resolution monitoring satellite could be placed in geosynchronous orbit to support modification experiments.

Socio-Economic Benefits

The potential economic and social benefits to be achieved by increased capability in predicting weather and climate changes are incalculable and immense. Examination of the expected impacts of improved predictions on the total U.S. economy indicates short term benefits in the hundreds of millions of dollars, e.g., through increases in agricultural productivity and the reduction of property losses. When indirect, intangible, or long term benefits are considered, 100 million dollars might be an insignificant sum indeed. And if our estimates are extended world-wide, the numbers would probably appear unbelievable to today's observer.

1. Economy

A number of estimates have been made in recent years on the economic benefits associated with existing weather services and at least one which assesses the economic benefits of extending the range of weather forecasting to three months. Total annual losses from adverse weather have been estimated at over twelve billion dollars with more than five billion dollars potentially savable with adequate warnings sufficiently in advance of the weather events.1/ Table 1 summarizes the effects of adverse weather on the total U.S. economy.

The potential annual savings attributable to longer-range weather forecasts increase sharply from short term (1-5 hours) to three month forecasts. The total estimated annual savings represent only about 14% of the total protectable losses due to the cost of protection. Further gains could come only from modifying the weather itself. The savings available, especially to agriculture, from forecasts ranging from ninety days to one year, while not now quantified, should increase enormously.

These estimates deal with economic benefits associated with adverse weather. A vastly different scenario must be written for the economic impact of long range weather forecasts, and yet another for the prediction of climate change and its economic impact. The latter subject not only encompasses periods of dozens of years, but the effect of such changes in many cases will not be measureable for additional dozens of years. Thus, any attempt to assign numbers to the economic effects of climate perturbations is very difficult. The rough order of magnitude of climate change effect has been illustrated in estimates which find a 1°C decrease in ambient temperatures causing changes in annual expenditures in the U.S. economy alone of billions of dollars.2/ A similar order of change may be expected from changes in wind intensity, pollution's effects, precipitation or sea level changes.

1/ J.C. Thompson, The Potential Economic Benefits of Improvements in Weather Forecasting, California State University, San Jose.

2/ U.S. Department of Transportation, Proceedings of Third Conference on the Climate Impact Assessment Programs, February 26-March 1, 1974, Washington, D.C., December 1974.

TABLE 1: ESTIMATED ANNUAL WEATHER DAMAGE - MAJOR U.S. ECONOMIC SECTORS 1/

SECTOR	LOSSES ($ Millions)	ESTIMATED SAVINGS ($ Millions)
Agriculture	8,240.04	567.0
Aviation	92.4	3.6
Construction	998.0	31.5
Communications	77.4	0.6
Electric Power	45.7	1.3
Energy	5.1	0.1
Manufacturing	597.7	20.0
Transportation	96.3	3.2
Government Enterprises	2,531.8	111.8
TOTALS	12,684.8	739.1

1/ J.C. Thompson, op. cit.

The chief direct economic benefit resulting from long range weather forecasting is optimizing decisions which bring cost savings in planning, distributing and gathering water resources. Knowing that heavy rains will fall in six months allows irrigation authorities to let all the water out of the reservoir during a drought rather than maintaining a reserve against continuing lack of rainfall. Knowing how much snow there is in a given area and how much rain there will be later in the growing season allows more water to be directed immediately into more hydroelectric power generation, reducing pumping costs to the area and making electricity cheaper to the surrounding area.

Knowing the weather several months beforehand will enable farmers to plant and harvest at optimum times and will enable the federal government to know whether to store, sell, or export. This will be further refined by knowing the weather and crop forecast world-wide. While the savings from the long term weather forecast cannot now be quantified for any appreciable time in the future, they would appear extremely large. In 1969, about 21 million acres were irrigated by the 50 states at varying costs. A total of $1,607,000,000 was invested in these lands.1/ The savings possible through reducing irrigation costs to this area through improved weather forecasting would appear substantial.

2. Energy

The application of long-range weather forecasting and climate prediction to the field of energy has far-reaching and profound economic implications.

Should long-range weather forecasting establish the validity of weather modification techniques, and such techniques prove sufficiently effective, the economic impact will be pervasive. Enormous amounts of solar power may be enacted through the dissipation of clouds, wind and tidal energy may be harnessed through forecasts and new knowledge of ocean and atmospheric currents and both new and existing energy resources will be better managed and thus more efficiently utilized.

3. Environment

Long-range prediction will aid in the planning of relocating overcrowded population and industrial centers. Understanding the physical basis of climate will permit climatic enhancement both through pollution control and deliberate climate changes.

4. Protection of Life and Property

Tornadoes kill, on the average, 107 persons in the United States per year. Hurricanes, hailstones, and severe local winds bring the total up to about

1/ U.S. Bureau of the Census, Statistical Abstract of the United States, 1975 edition.

600 lives lost per year. Reported property loss from tornadoes alone showed a 34 year average (ending 1955) of $13,612,226 per year. However, during the period 1965 to 1969, the average property loss from tornadoes exceeded $200 million per year. A 36 year average of property damage due to hurricanes in the period 1920 to 1955 was $100 million per year, but this did not inlcude Hurricane Agnes which alone caused $3.5 billion in property damage in 1974. Betsy, in 1965, and Camille, in 1969, each caused $1.4 billion in property damage while the combined property loss due to Connie and Diane in 1955 was about $1 billion.1/

The present loss of life figures have already been greatly reduced by the U.S. Weather Bureau warnings. To appreciate this, one only has to consider the 2,000 lives lost in Florida by a storm surge in 1928 or the more than 6,000 lost in Galveston in 1900. Yet, most of the lives and some of the property presently being lost could be saved by accurate short term (up to 6 hour) local forecasts.

Weather/climate forecasting will contribute to the abatement of natural disaster damage, promote the development of new types of construction to help reduce damage and generally prolong the useful life of capital goods. Some perils should be drastically reduced, e.g., drought, and to some extent, hail damage. Crop insurance will become generally available and other property insurance will offer broader coverages at lower cost. Longer range weather forecasting will result in substantial savings to sea transportation through optimum ship routing and improved short range, more accurate forecasting will substantially benefit air transportation. Climate catastrophies (e.g. temperature "inversions" over large cities) may be avoided. Substantial savings in health care costs may be expected and the general level of health and productivity raised.

5. Food and Natural Resources

In developing a system to make long range accurate weather predictions to benefit the United States, it will be necessary to develop satellites which collect relevant data around the world. Thus, there exists the distinct possibility of exporting weather forecasting services at a minimum marginal cost.

Every chemical and physical process related to plants is influenced by temperature. These include:

- solubility of minerals
- absorption of water, gases and nutrients
- diffusion
- synthesis
- growth
- reproduction

1/ U.S. National Oceanic and Atmospheric Administration, Climatalogical Data: National Summary, 1973 and 1974 editions.

In addition to temperature, the water supply and amount of sunlight are major factors affecting plant growth.

All of the world's food that comes from plants is grown on 4 billion acres of cultivated soil. It would require substantial amounts of capital to bring additional presently non-arable land under cultivation. While no wide-area estimates on water's contribution to the costs of reclamation are available, substantial data exists for the cost of reclaiming land in local project areas.

A 1970 study by the Oak Ridge National Laboratory for the U.S. Atomic Energy Commission on water resource development in Egypt indicated reclamation costs varying from $160 per acre for an 83,000 acre development near the Delta to $870 per acre for a 21,000 acre tract east of Suez. Earlier completed project averages $465 per acre, of which 60% ($200 per acre) was used for reclamation operations (research, land leveling, irrigation and drainage facilities) and 40% ($185 per acre) for rehabilitation of facilities (housing drinking water, lighting, internal roads). The cost of the water supplied to this project in the late 1960's was 2.6¢ per 1000 gallons. 1/ A crop of wheat requires about 543,000 gallons of water per acre to yield fully, or over $1400 per acre. 2/ In areas with moderate rainfall, the cost of water is considered zero.

There were, in 1974, 16,369,428 acres of irrigable land in the U.S., under the control of the Bureau of Reclamation and 9,418,223 acres were actually irrigated by Bureau projects. The total gross crop value for this land, all of which was made arable by the Bureau of Reclamation's irrigation projects, was $4,655,242,691 in 1974 or $494.28 per irrigated acre. 3/

Thus, it does not appear to be cost-effective to greatly increase the food supply by the reclamation of land at current costs. The other possibility then, is to increase the yield of the present arable land. Long term weather forecasting would be very beneficial in this effort.

6. New Knowledge

This application should add immeasurably to understanding the dynamics of weather and climate, their physical basis and origin and the effects of man-made disturbances. New forces may be discovered and an understanding gained of the mechanics of the sun and the circulation of oceanic and atmospheric currents as well as the state of the stratosphere. New statistical models will be developed and new knowledge will be acquired on intra-atmosphere, cloud physics and mesoscale phenomena and microphysical phenomena.

1/ D.S. Pastir, Land and Water Resources Development in Egypt, Oak Ridge National Laboratory, Dec. 1970

2/ Nuclear Energy Centers, Industrial and Agro-Industrial Complexes, Summary Report Oak Ridge National Laboratory, July, 1968.

3/ U. S. Bureau of Reclamation, Water and Land Resource Accomplishments, Statistical Appendix 1, 1974.

Relationship to NASA/OAST Space Technology Goals:

An effective weather and climate prediction program will require great technological advances in information acquisition and information management. In addition to the myriads of data processing activities required on the ground, on-board data processing equipment and sophisticated data compression techniques must be developed.

Sensor technology, principally in the active microwave area, must be developed.

Relationship to National Needs

Long range weather and climate prediction capability supports each of this study's national needs. Substantial and pervasive benefits to the economy will follow the development of capability for long range weather and climate prediction. Adverse weather damage prevention, increased agricultural productivity, improved public works planning, new sources of energy, (solar, tidal and wind) and the advantages of large food surpluses to create new world markets, new jobs and more disposable income are a few. New industries may be created including the weather forecasting technology industry.

Knowing the climate of the future will generate substantial cost savings in the allocation of energy resources and permit the development of solar, tidal and wind energy.

Public works planning will be made more effective. We will better understand the manner in which pollution effects oceans and the atmosphere.

Weather is the largest factor in food production. Large food surpluses should result from long range forecast capability.

The world's nutrition, general health and, perhaps, productivity will be raised significantly. Underdeveloped nations will be able to industrialize.

Scientists will better understand the dynamics of weather and climate, discover new forces, learn the mechanics of the Sun and more about ocean and atmospheric currents, the role of the stratosphere, cloud physics and microphysical and mesoscale phenomena.

Summary and Conclusions

- By 1985, an operational system could be implemented, based on the GARP global experiment. The network would include 2 to 4 satellites on near-Earth, Sun-synchronous orbit and other satellites in geostationary orbits. Existing facilities for weather and climate observations would be incorporated.

- The effects of weather and climate on all of society are universal. Longer range and accurate forecasts of weather and climate changes will be totally pervasive. Such forecasts will improve crop productivity, reduce losses of life and property, create new industries, improve safety, reduce costs of public planning efforts, and benefit many other undertakings.

- The potential socio-economic gains of improved weather and climate forecasting are so great and so obvious that the recommendation for continued development of this capability is emphatic.

CROP PRODUCTION FORECASTING AND WATER AVAILABILITY

TABLE OF CONTENTS

Application: Crop Production Forecasting and Water Availability

Background:

Food and water are vital to human existence. As the population increases the need for food increases. Food production requires water availability.

The world's population has grown steadily since the agricultural revolution; in the last two centuries the rate of growth has been exponential. Based on constant fertility and no global disasters, a threefold population increase is possible in the next half century. Hopefully, the population increase will be curbed, particularly in the so-called underdeveloped countries, by increased awareness of the problem, through education, and eventually, if necessary, by geopolitical action. In any event, the population will continue to grow and, accordingly, the need for food.

On a global scale there has been a striking decrease in grain reserves, which have fallen from sixty days in 1961 to about twenty days at the present time. Only North America is a major surplus-producing region. Even there the margins are so small that even relatively minor changes in weather and distribution patterns can produce large fluctuations in the availability of food.

The total availability of food production in any given year is a necessary piece of information. However, for a total food resource program it is necessary to know much more. Where is it? When will it become available? How much of it will be usable? And how can it be transported to the market place and, hence, to the consumer?

There must be a continuous inventory of present arable land - its location, cultivatable characteristics, types of crops produced, and percent of usage. The search for new arable land must continue.

Similarly, an inventory of livestock resources must be maintained. Availability to the market place will be essential. It is necessary to plan in advance airlift feed programs to prevent herd loss in the event of untimely weather conditions.

Water availability is the key for agricultural production. It will be necessary to identify and catalogue water sources, to predict seasonal and yearly variations, to determine where dams should be erected, and their operational usage.

Improved forecasting of weather and water availability would increase food production. Since food exports are a major factor in U.S. world trade and balance of payments, better crop production forecasting could provide data pertinent to trade agreements, market changes, early warning of crop failures, and transportation planning.

Objectives:

The objectives of this application are twofold.

1. Crop Production Forecasting

The goal is to provide satellite survey systems to provide data to ground processing facilities which, with information gained from other sources, will provide a biweekly forecast of the global production of major crops having world-wide food and/or economic significance.

2. Water Availability

The objective is to utilize space satellite surveys of snow and moisture to provide forecasts of water availability for irrigation, hydroelectric power generation, and large-scale shale oil processing.

Program Summary:

1. Crop Production Forecasting

Earth-orbiting space systems offer a feasible, systematic approach to global crop production forecasting. The Large Area Crop Inventory Experiment (LACIE), now underway, represents a desirable first step. Based on existing satellite systems, crop inventories are being obtained, pattern recognition techniques are being tested, and yield models are being developed. A degree of operational capability may be developed in the next several years.

An operational satellite system for global wheat forecasting is projected for 1982. Later in the decade an improved system could be operational for forecasting the production of all major crops. Since non-wheat crops usually use smaller fields higher resolution sensors will be required.

Passive sensors will initially be used. They will require cloud-free conditions to gather data. A large number of earth-orbiting satellites will be needed to ensure adequate frequency of measurement. An all-weather system, using active microwave sensors, would be developed in the 1990's.

The capabilities required are:

- improved yield models
- optimal sampling strategies
- sensors with high signal-to-noise ratios
- more complete predictive models

2. Water Availability Forecasting

Water availability in the U.S. appears adequate to the end of the century, but large regional insufficiencies, particularly in the West, are likely. The primary water source in this area is snowfall and melt in mountain regions. Current forecasts of these sources have errors of the order of 25%; this allows a large amount of usable water to be lost.

The target date for an operational satellite system is 1982. It would use space data provided by the same satellite as used for global crop forecasting.

An improved operational system would involve surveys of soil moisture, snow moisture, and water. It could use passive or active microwave sensors operating at several frequencies. Large antennas, hundreds of meters in diameter, will be required, particularly for the passive systems.

Socio-Economic Benefits of Crop Production Forecasting

Much of the world's population today goes hungry although in varying degrees. Many leaders are alarmed to see a sharp drop in food surpluses during the last two decades. Tragic consequences may result from wrong assumptions that food needs will be met through normal processes.

United States food production may not sustain our own population beyond 1990. Decades will pass before the less developed nations will have adequate nutrition even with the most optimistic projections for present global food producing capabilities.

Improved forecasting technology will contribute to more productive management of our renewable resources. Estimates for increasing the food supply are only approximate, yet the potential benefits are enormous.

1. Economy

a. Benefits to Agriculture 1/

Domestic agricultural crops and livestock represent over 6% of our gross national product (over $60 billion). Current economic losses resulting from less-than-optimum management of these resources may be attributed to inadquate knowledge of such factors as expected production, pest and disease infestation and market operations. This knowledge gap results in annual losses in grain production. Estimated loses for wheat and soybeans are shown below.

TABLE 1: ESTIMATED ANNUAL LOSSES AVOIDABLE BY IMPROVED CROP PRODUCTION FORECASTING

CROP	Estimated Avoidable Losses ($ Millions, 1973)	
	Lower Bound	Upper Bound
Soybeans	71	337
Wheat	35	212
Totals	106	549

Major benefits should follow from improved information concerning these factors. Cost savings would be available to the federal government in obtaining data on agricultural resources. The substantial benefit of

1/ Substantial portions of this section were adapted from, G.A. Hazelrigg, Jr., J. Andrews, et.al, The Economic Value of Remote Sensing by Satellite..., ECON, Inc. Princeton, N.J., December 1974.

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improved management decisions accrue from improved agricultural crop statistics and previously unavailable crop data. These result primarily from improvements to the Department of Agriculture's domestic crop production forecasts. Data provided by satellites will enable farmers to make better use of agricultural lands, identify levels of crop vigor and reduce losses from insects or week infestation.

Estimates have been made on the potential uses and economic gains of a satellite-based earth resources monitoring system based upon an exhaustive study of research on this subject since 1952 and, additionally, on an independent evaluation for the benefit to agriculture based upon a detailed case study. The economic value of the system was obtained by aggregating non-overlapping benefits derived from the major components of the U.S. agronomy, among other major areas of total national resources such as forestry, minerals and fresh water resources. Total economic gains were estimated annual gains for agriculture ranged from $726.3 million to $1511.7 million projected to 1985. These figures are expressed in 1973 dollars. Current annual economic benefits (1973 dollars) accruing to agriculture are estimated from $253 million to $555 million based upon the hard benefits documented by case studies. Soft benefits estimates of from $474 - $957 million annually are projected. These soft benefits are estimates derived from many other economic studies, many of them earlier, but considered to be valid.

Many subsystems in agriculture, water resources, crop land allocation, and distribution, comprise the system of crop forecasting. A summary of economic gains which may be expected from satellite data in the agricultural sector are presented in Table 2

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TABLE 2: AGRICULTURAL BENEFITS

FUNCTION	BENEFITS ($ millions - 1973)
Soil Surveys	(37) 1/
Crop Inventory, Acreage and Yield Measurements	251-553
Worldwide Crop Product Distribution	(265-471)
Specific Crop Land Allocation	(15-119)
Water Shortage Avoidance	8.3
Soil Conservation	(82)
Crop Disease Prevention	(38)
Insect Infestation Prevention	(18)
Weed Infestation Prevention	(2.4)
Crop Damage Assessment	(1.3)
Disaster Early Warning	(200-508)
International Trade Opportunities	(200-500)
Research	(82.2)
Government Compliance	(15.8)
Total Land Benefits	252-554
Total Additional Soft Benefits	474-957

1/ Soft benefits are shown in parentheses.

Source: G.A. Hazelrigg, Jr., J. Andrews, et.al., op, cit.

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The major hard benefits would come from improvements in measuring crop acreage, inventory, and yield. This amounts to an optimistic estimate of over half a billion dollars annually (in 1973 dollars). Improvements in world-wide distribution of crops produced by the United States generate the major soft benefit, optimistically at 471 million (1973) dollars and conservatively at 265 million (1973) dollars. Very substantial soft benefits are also produced by various soil surveys and early warning of disasters such as massive insect attack,and unique international marketing opportunities for domestic agricultural products, perhaps as high as one billion dollars per year or more.

b. Benefits to Other Industries

In the initial years of operation, the total expected economic gains (in 1973 dollars) deriving from gains in both distribution and production will total $250 million. After another 10 years, an additional gain of $250 million may be expected.

During the initial years of operations of the earth resource survey capability, economic benefits will accrue mostly in proportion to value added or sales throughout the agricultural sector of the U.S. economy, including both farmers and consumers. After another ten years have elapsed from this initial period, the competitive effects in the U.S. agricultural sector should benefit consumers through dampened price movements, and the farmer through increased income and better production decisions. Table 3 lists these benefits.

c. Potential Benefits to Other Earth Resources

The applications of satellite sensing technology to such areas as rangeland and timber inventories, land allocation forest product inventory and harvesting decisions are estimated at $54.5 million annually with an additional $62.2 million possible from soft benefits. Activities such as mapping potential water impoundment areas, fresh water inventory, pollution monitoring, and flood control will generate gains estimated at $57.2 million. Cost savings in mapping required by federal and state land use statutes are estimated at $7.9 - 37.1 million. The mapping and management of the non-renewable natural resources (minerals and petroleum) including their exploration and extraction will produce a gain of $1.6 - 3.9 million dollars, and additional soft benefits of $33 - 77 million. Air pollution, and weather research benefits are estimated at $1.5 - 10.5 million and soft benefits of $6.4 - 31.2 million. Gains from activities relating to the oceans will come chiefly from ocean food resource development and will be about $1.7 - 4.2 million with additional soft benefits of $5.0 - 12.7 million. All told, the economic gains projected for the next 10 years amount to $1,027,800,000 to $1,972,700,000 annually.

TABLE 3: AGRICULTURAL BENEFITS-EFFECT ON OTHER INDUSTRIES

INDUSTRY	PRODUCTION AND DISTRIBUTION GAINS ($Millions - 1973)	
	Initial Period	Ten Years Later
Tobacco	10	
Food	52	
Lumber	3	
Forestry	1	
Textiles	12	
Agriculture	74	18
Agricultural Services	4	
Federal Gov't Expenses	5	
Real Estate	14	57
Households	25	175
TOTALS	250	250

Source: G.A. Hazelrigg, Jr., J. Andrews, et. al., op cit.

TABLE 4: NET ANNUAL BENEFITS - WATER RESOURCES

FUNCTION	OPTIMISTIC ESTIMATE OF BENEFITS ($Millions - 1973) 1/
Surveys of Water Resources 2/	6.4 (17.3)
Prediction of Water Supplies 3/	1.4 (35.9)
Monitoring Changes in Water Supplies 4/	.8 (5.7)
Management of Water Storage 5/	54.8 (28.8)
Damage Assessment and Prevention 6/	.6 (4.4)
Disaster Recognition and Early Warning 6/	.6 (5.0)
Hydrological Research	(12.7)
Government Regulation, Projects and Planning	(4.3)
Total Hard Benefits	57.2
Total Soft Benefits	(121.1)

1/ Soft benefits are shown in parentheses

2/ Includes snow, ice, glacier surveys, potential water storage and pollution surveys

3/ Prediction of water supplies, floods, pollution levels

4/ e.g., ice cover, soil moisture, cylical pollution patterns and evapotranspiration

5/ Includes water for agriculture, cities and power generation

6/ Floods, pollution, insects, disease

Source: G.A. Hazelrigg, Jr., J. Andrews, et.al., op, cit.

d. Water Resources

Until fairly recent times, our water supplies were treated as if without cost. Rapid urban and industrial growth has greatly changed the view. Not only are water resources becoming scarcer through depletion and the ravages of pollution, but increasing population presses flood plains into use making flood control more difficult and expensive.

Better prediction of water supply through space sensing of snow cover, glacier activity, soil moisture, and water runoff will allow the release of additional water which may be used for irrigation which will produce an annual benefit of $8.5 million to the Western United States (a 10 state area was used for this estimate). Additional benefits from this water for the production of electric power yields an estimate, judged as conservative by the investigators, of $4.2 million per year for the nation as a whole.

The increased data gathering capability resulting from currently available (but not fully developed) satellite technology should result in national economic gains of the order illustrated in Table 4. Substantial additional benefits may be expected from increased capability to predict weather with the degree of accuracy of present day weather forecasts but for periods of up to one year. Accounting for the greatest proportion of benefits is the improved decision-making associated with water supply management made possible by new measurement data provided by satellite. Hard benefits at the upper bound of the estimates are set at $54.8 million. The prediction and measurement of water supplies, flood and eutrofication disaster and hydrological research suggest additional soft benefits will be realized amounting to 121.1 million dollars.

The new technology of weather/climate forecasting and modification should develop into a major exportable commodity for the United States and an important domestic industry which might well stimulate the development of diffuse new industries. This technology may become an important item in our foreign aid program especially to the less developed nations. Understanding the causes of famine, how to manage grazing lands and marine and fresh water food resources, and the preservation of rare and exotic species will all contribute to our foreign aid and diplomatic mission to the less developed nations.

An optimistic summary of the economic benefits which might be expected from satellite based capability in observing and measuring earht resources, both renewable and non-renewable, is presented schematically in Figure 1 by principal resource management function. The estimated gains by major impact area are totaled and subtotaled in Table 5.

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FIGURE 1: BENEFITS FROM IMPROVED MANAGEMENT OF EARTH RESOURCES
($ Millions)

	Agriculture	Forest	Water	Land Use	Nonrenewable Resources	Atmosphere	Oceans	Totals
Measurement								
Survey	37.0	4.9	29.8		3.9	10.5	12.7	98.8
Damage Assessment	1.3							1.3
Research	82.2	22.4				.1		104.7
Monitoring	15.8		7.3			27.0		50.1
								254.9
Prediction								
Future Supplies			.6					.6
Conservation						.3		.3
Disaster	250		4.3					254.3
								255.2
Prevention								
Disease	49		.7			2.9		52.6
Insect Infestation	4.2							4.2
Disaster			10.4					10.4
								67.2
Control								
Resource Allocation	118.8	87.3	75.7	37.1				318.9
Production & Consumption			.4		78			78.4
Distribution	1444.0							1444.0
								1841.3
Totals	2002.3	92.2	151.6	37.1	81.9	40.8	12.7	2418.6

Source: G.A. Hazelrigg, Jr., J. Andrews, et.al., The Economic Value of Remote Sensing by Satellite ..., ECON, Inc., Princeton, N.J., December 1974.

TABLE 5: BENEFITS FROM IMPROVED MANAGEMENT OF EARTH RESOURCES
($ Millions)

Measurement $254.9	Prediction $255.2	Prevention $67.2	Control $1841.3
Survey $98.8	Future Supplies $0.6	Disease $52.6	Resource Allocation $318.9
Damage Assessment $1.3	Conservation $0.3	Insect Infestation $4.2	Production $78.4
Research $104.7	Disaster $254.3	Disaster $10.4	Distribution $1444.0
Monitoring $50.1			

Source: G.A. Hazelrigg, Jr., J. Andrews, et.al., The Economic Value of Remote Sensing by Satellite ..., ECON, Inc., Princeton, N.J., December 1974,

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2. Energy

The expanded data base from satellite observations will enhance the development of new sources of energy. Among the possibilities are tidal, wind, solar and geothermal sources. New data and modeling will enable scientists to predict wind and tides, cloud cover and geothermal occurrences. Improved forecasting permits savings due to energy resource management. More and cheaper energy supplies will produce cost savings to almost all industries and to consumers primarily through lower fuel, transportation and food costs, and also through lower prices on most manufactured goods.

3. Environment

Satellite based forecasting may be expected to substantially improve air and water quality through the enhanced ability to supply and manage water resources and to monitor and abate atmospheric pollution.

4. Protection of Life and Property

The chief benefits associated with this national need are includable under the Weather/Climate systems application.

5. Food and Natural Resources

Benefits will derive from more and better food at lower prices more equitably and efficiently distributed. Adequate food supplies should lead to rapid industrialization of the less developed nations and the creation of new world markets. Present day levels of food supplies may insure that the underdeveloped nations are always underdeveloped and that their populations barely survive.

Improved forecasting technology will also make significant contributions to the discovery and management of non-renewable natural resources such as minerals and petroleum, ocean resources, forest product, wildlife protection.

6. New Knowledge

The availability and timing of vast quantities of new data will spawn valuable new mathematical models for greater accuracy and longer range predictions of food and water supplies.

Spacecraft observations will greatly benefit the science of archeology.

Relationship to National Needs

The Crop Production Forcasting system would support all the National Needs applicable to this study.

The economy will be benefited by larger food supplies at lower prices, more efficiently distributed. Exploration of minerals and petroleum will be made less costly. Crop insurance should become generally available.

The expanded data base will aid in the development of new sources of energy e.g., wind, tidal and geothermal. Improved water resource management will increase hydroelectric power generation. More and cheaper energy supplies will produce cost savings to all industries and also to consumers.

Environmental protection is strengthened through the utilization of remote sensing devices and satellites to monitor and control air and water pollution.

Life and property will be protected by foreknowledge of impending natural disasters.

New knowledge gained from vast quantities of new data almost instantly available, will permit the development of new and highly valuable agrometric models. This new technology is applicable to the entire earth resource spectrum.

Relationship to NASA/OAST Space Technology Goals:

Improved technology and methods in information acquisition and management will be required to meet the objectives of this program. On-board data processing and data compaction must be used. Sensor development, particularly for active microwave instruments, will be needed for the ultimate system as well as the erection of a very large antenna system in space.

Summary and Conclusions

- Satellite systems offer a feasible and systematic approach to greatly enhanced capabilities for crop forecasting, resource management, and water inventory observations.

- Increasing world food needs, declining surpluses, and rising prices will require major efforts to increase productivity of food production and watér management - to sustain our economy and to help other nations.

- The system will involve multi-sensor satellites, other earth-and atmosphere-borne sensors, large data transmission and processing capabilities, optimal sampling strategies, sensors with high signal-to-noise ratios, large antennae in space, and further improved predictive models.

- Economic benefits from improved management of earth resources may easily exceed $2 billion annually. Social benefits may be even greater. The satellite systems would cost only a fraction of such sums.

- This system is needed, its implementation should be pursued urgently.

PLANETARY ENGINEERING OF THE PLANET VENUS

CONTENTS

Application: Planetary Engineering of the Planet Venus

Background:

Some time in the next millênium, our expanding population and the continuing growth of industrial needs may tax the resources of the Earth to the limit or beyond. In this event, in order for our civilization to grow or even exist, it may be necessary to establish colonies on other heavenly bodies. A terrestrial catastrophe, brought about, for example, by the close passage of or even potential impact with a large, wandering, heavenly body, could also require such an exodus.

The planets Venus and Mars as well as Titan, a large satellite of Saturn, the only satellite in the Solar System known to have an atmosphere, are potential candidates for colonization. Since the atmosphere of Mars is extremely thin and since Titan is so remote from the Sun that its low temperatures would hamper human existence, it would appear that Venus is the prime candidate for mass human colonization.

Venus, particularly when our knowledge of its characteristics was fragmentary, was sometimes thought of as a twin planet to the Earth. The sizes, masses, and densities of the two are comparable. Venus approaches closer to the Earth; with the exception of the Moon, the asteroid Eros, and, occasionally, a passing comet; than any other body. Venus is closer to the Sun, but not appreciably so.

However, as a habitable body for man, Venus differs from the Earth in several important respects, particularly in the extreme heat of the surface and the chemical properties and dynamics of its atmosphere. By the application of Planetary Engineering, it is within the capabilities of mankind to correct these deficiencies.

Objective:

The objective of this application is to apply the principles of microbiological planetary engineering to so alter the surface characteristics and the atmosphere of the planet Venus as to make it habitable for man and the animal and plant life necessary for his survival.

Mission Summary

As we shall see, the surface of Venus, due to the so-called greenhouse effect, is extremely hot - in the neighborhood of 300-600°C. Consequently, in addition to other negative effects, no free water could be present on the surface. Venus is completely cloud-covered; its atmosphere is constituted largely of carbon dioxide, nitrogen, and water vapor in the form of ice crystals and droplets.

To make Venus habitable for man it will be necessary to lower the surface temperature, thus making free water available; to lower the percentage of carbon dioxide present in the atmosphere; and to increase the abundance of molecular oxygen. This could conceivably be done chemically or biologically. The ability to transport large amounts of chemicals to Venus would make this method practically impossible. Carl Sagan, the Cornell astronomer, has proposed a method to alter the atmosphere of Venus using microbiological forms.1/

1/ I. S. Shklovski and Carl Sagan, Intelligent Life in the Universe, Holden - Day, 1966, pp. 467-8.

Since the necessary ingredients for photosynthesis - light, water vapor, and carbon dioxide - are present, the seeding of the atmosphere of Venus with appropriate microorganisms, probably some form of blue-green algae, along with subsequent reactions, would in time achieve the objective.

Many species of blue-green algae are remarkably resistant to extreme heat. They have been found living and flourishing at temperatures approaching the boiling point of water. There are temperatures in the Venusian atmosphere suitable for their life processes.

Some species of blue-green algae are nitrogen-fixers, that is, they have the capability of combining atmospheric nitrogen into compounds suitable for plant food. This would significatly decrease the amount of material that would have to be transported.

These cultures of blue-green algae would be transported to Venus and released at a suitable altitude. The density of the atmosphere and the convective currents present would keep the microorganisms in the atmosphere long enough for the process of photosynthesis to occur. The fact that blue-green algae require no sexual process and reproduce solely by cell division, also eases the problem.

As the algae slowly sink to lower levels, they will burn up. In this manner, carbon and other useful elements and compounds will be deposited on the surface.

Socio-Economic Benefits or Necessity

The socio-economic benefits of a program to alter the atmospheric characteristics of Venus in such a way as to render the planet habitable to man are not measurable in the same sense as other applications. The desirability of such a program in the next millenium may well be a matter of survival of the human race. Such a requirement would dwarf any other socio-economic benefits to be derived from such a program. It is difficult to assess when the desirability for colonization of another body will become an absolute requirement but, for planning purposes, it would be well to achieve the total capability in the next millenium.

There are certain potential developments which could establish such a requirement. These are:

- The imminent approach of an alien body
- Overpopulation and consequent depletion of food resources
- Consumption of nonrenewable natural resources due to increased technology
- Possible pollution of our own atmosphere

The approach of an alien body could be one possible explanation for some of the changes in the Earth's physical characteristics during the ages such as: the tilting of the Earth's axis resulting in the Ice Age and changes in the climatic profile of the Earth; the apparent increase in volcanic and tidal wave activity about 20,000 years ago; and the disappearance of continental masses and chains of land connecting the continents.

It seems impossible for any body in the present Solar System to approach the Earth in such a manner as to cause destruction or annihilation. However, there are probably many large massive objects travelling through space which are independent of any such system. If one were to approach the outer limits of the Solar System, the large gravitational attraction of the Sun could so alter their orbits that they may pass dangerously close to, or actually collide with Earth. A close approach could cause earthquakes, tidal waves, and the actual breakup of land masses. A collision could result in total destruction.

The presence of such a body would probably be known to us when it approached the outer limits of the Solar System, at which time its disk would be illuminated by the Sun. At that time we could start to compute its orbit and assess any potential danger to Earth. It could still be decades or even centuries before a confrontation would take place--enough time to effect colonization of another body if the necessary preparations had already been made.

A remote possibility, yes--a feasible occurrence, also yes.

The other possible developments are perhaps closer to home. We can almost think of the Earth and its capability to provide resources as finite and the population growth and consequent need for its resources as almost infinite.

World population is increasing super-exponentially, that is, the rate of growth is increasing. If there is no appreciable change in either fertility or mortality, the year 2500 will see a world population of over 20 billion people.

The supply of food for this population will be limited by the amount of photosynthesis of plant life taking place. Mankind probably cannot do much about increasing the efficiency of sunlight. However, in addition to the continuing need for carbon dioxide and water, we will have a need for additional arable land. The costs involved in making new land productive and finding adequate supplies of water are very high.

The capital which will be required to develop this new land will come from expanded industrialization. While industrialization is also increasing exponentially, it is questionable whether its growth can keep pace. The growth of industrialization has also caused pollutants, in those areas where they have been measured, to increase exponentially. Their effects, additionally, are almost certainly underestimated because of the natural delays present in ecological processes. The upper limits of pollution which may be reached before serious damage to the ecosphere occurs are presently unknown.

An improved condition would be expected if it were possible to stabilize population growth and industrialization. However, this will not prevent the eventual exhaustion of the world's supply of minerals and petroleum.

The power of technology and geopolitical actions to solve these problems is uncertain.

Other socio-economic benefits from such a program will accrue. The laboratory research on algae and photosynthesis will result in improvements in agricultural productivity here on Earth. A further understanding of the atmosphere of Venus and the methods to be used for altering it will improve our ability to improve our own ecosphere.

In summary, it appears that mankind will have to provide himself the capability to escape to or colonize other bodies in the Solar System. The planet Venus appears to be the most desirable for such purposes.

Initially, we are not proposing to provide a Utopia - we are talking about survivability. However, a new civilization on a new planet may, as it develops, avoid the errors mankind has made on Earth and, indeed, become a near-paradise.

Technical Background:

1. The Planet Venus

Venus is the second planet outward from the Sun. It comes closer to the Earth than any other planet - 40.086×10^6 kilometers at its closest point. A comparison of certain orbital and physical characteristics of the two planets follows.

	Venus	Earth
Mean Solar Distance	0.723 A.U. 108.2×10^6 kms.	1.0 A.U. 149.6×10^6 kms.
Orbital Period	224.7 days	365.25 days
Mean Orbital Velocity	35.05 kms./sec.	29.79 kms./sec.
Period of Rotation	247 days retrograde	1 day
Mean Radius	6100 kms.	6378 kms.
Mass	4.869×10^{27} gms.	5.977×10^{27} gms.
Mean Density	5.158 gms./cm.^{3}	5.517 gms./cm.^{3}

Venus has frequently been thought of through the years as a twin planet of the Earth. Considering the above characteristics, the only appreciable difference between the two is in the rotation period which, for Venus, remained unknown until the advent of radar. We shall note other important differences, particularly in surface and atmospheric properties, as we proceed.

Since Venus has a very dense atmosphere and is completely covered by clouds, we have no visual knowledge of its surface features. However, sufficient information has been gained from radar mapping and planetary probes to establish that the surface is quite forbidding by terrestrial standards. The surface pressure is about ten times that of the atmospheric pressure on Earth and the surface temperature is about 300-500°C.

An internal model of Venus has been proposed by K. E. Bullen[1/], which is similar to that of the Earth.

	Venus	Earth
Liquid Core	21.5% by mass	31.5% by mass
Solid Mantle	75.4% by mass	67.6% by mass
Crust	3.1% by mass	.9% by mass

1/ Handbook of the Physical Properties of the Planet Venus, NASA SP 3029, 1967 - pgs. 32-33

G.J.F. MacDonald[1/] speculates that the internal structure of Venus is similar to that of Earth, except that the high surface temperature has caused liquefaction of the material in the outer mantle regions and, consequently, has introduced considerable body-tidal dissipation of energy from the solar-tidal interaction. The tidal forces decelerate the planet and account for the slow rotation rate. The retrograde rotation has not been explained.

Venus has no known satellite.

2. The Atmosphere of Venus

To understand the atmosphere of Venus, astronomers first had to account for the extremely high surface temperatures.

A theoretical estimate of the surface temperature of Venus, based on its distance from the Sun and its albedo (the ratio of electromagnetic radiation reflected by a body to that incident upon it) of 0.73, yields a value of about 235°K. Since this does not take into account atmospheric screening, the actual temperature should be somewhat higher. Present determinations indicate that the surface temperatures are 500-700°K.

Starting in the 1920s, repeated measurements have been made of the infrared radiation emitted by Venus. They also indicate a temperature of about 235°K. Since the clouds in the Venusian atmosphere, like our own, probably absorb all infrared radiation, these temperatures refer to the cloud tops and not the surface.

Radio telescopes have now measured the radiation emitted by Venus in the microwave region. Microwaves can pass freely through clouds without being absorbed. Thus, those observations should refer to the surface of the planet. The results indicated a surface temperature of over 575°K.

Three hypotheses could account for this result: (1) the microwave radiation was actually emitted by an electrically-charged ionosphere, (2) a very strong greenhouse effect, or (3) the presence of large quantities of dust. While the Mariner II spacecraft was passing Venus in 1962, its microwave radiometer looked straight down toward the surface, and also looked at an angle toward the edge of the planet and the atmosphere above it. Much higher readings were taken looking straight down. Thus the hot-ionosphere hypothesis was eliminated. Its readings also showed an even higher surface temperature of about 700°K.

There is now general agreement that a strong greenhouse effect of Venus' atmosphere exists--much stronger than a similar effect on Earth. Essentially, almost all of the Sun's radiation reaches the surface, but large amounts of carbon dioxide and water vapor in the atmosphere prevents the escape of most of the surface radiation back into space. Since the clouds of Venus cover the entire sky, their contribution to this effect is substantial. However, this is not enough as the presence of radiation-blocking gases still had to be established.

1/ Ibid., pgs. 34-35

Repeated spectroscopic readings have found evidence of large amounts of carbon dioxide in the atmosphere of Venus. However, carbon dioxide itself would not screen all the wavelengths necessary to establish the greenhouse effect. Balloon-borne spectrography first established the presence of water vapor in the planet's atmosphere in 1962. The Soviet probe of 1967 bore this out and reported just enough water vapor to trap the additional heat. Therefore, the tops of the clouds are probably ice particles and not dust or other solid material. Thus, the very high surface temperatures of Venus are a result of the greenhouse effect.

Atmospheric pressure on the surface of Venus is much greater, at least ten times the pressure on Earth. The atmosphere itself is about 30 times as dense as that of the Earth.

Much remains to be learned about the properties, composition, and dynamics of the atmosphere of Venus. Many authors and papers have treated this subject and have constructed models based on the data available. The model we shall use for this paper (Figure 1) represents a composite of this information. It is a graph of temperature (°K) versus altitude (kilometers) and pressure (bars) with structure levels and other properties as shown.

The surface is red-hot, surrounded by a densely-clouded gaseous envelope in four levels:

Level	Altitude (kms)	Temperature (°K)	Pressure (Bars)
I	0 - 30	525 - 675	$10^1 - 10^0$
II	30 - 60	375 - 525	$10^0 - 10^{-1}$
III	60 - 80	275 - 375	$10^{-1} - 10^{-2}$
IV	80 - 130	200 - 275	$10^{-2} - 10^{-5}$

The first level is clear in the upper portion with blowing dust near the surface. The second level consists of very dense clouds with extreme heat by terrestrial standards. The third level, the one of most interest to us, is composed of dense clouds with moderate temperatures. Ice crystals are present in the upper portion and water droplets in the warmer lower portion. The upper level consists of lighter clouds and haze.

For purposes of this paper we have assumed an atmosphere as follows:

Nitrogen	--	90% by volume
Carbon dioxide,	--	10% by volume
Water vapor,	--	.001% by volume

Traces of O_2, O_3, Ar, CO, NH_3, NH_4, etc.

This yields a molecular weight of about 29.62 and contains enough carbon dioxide and water vapor to support photosynthesis.

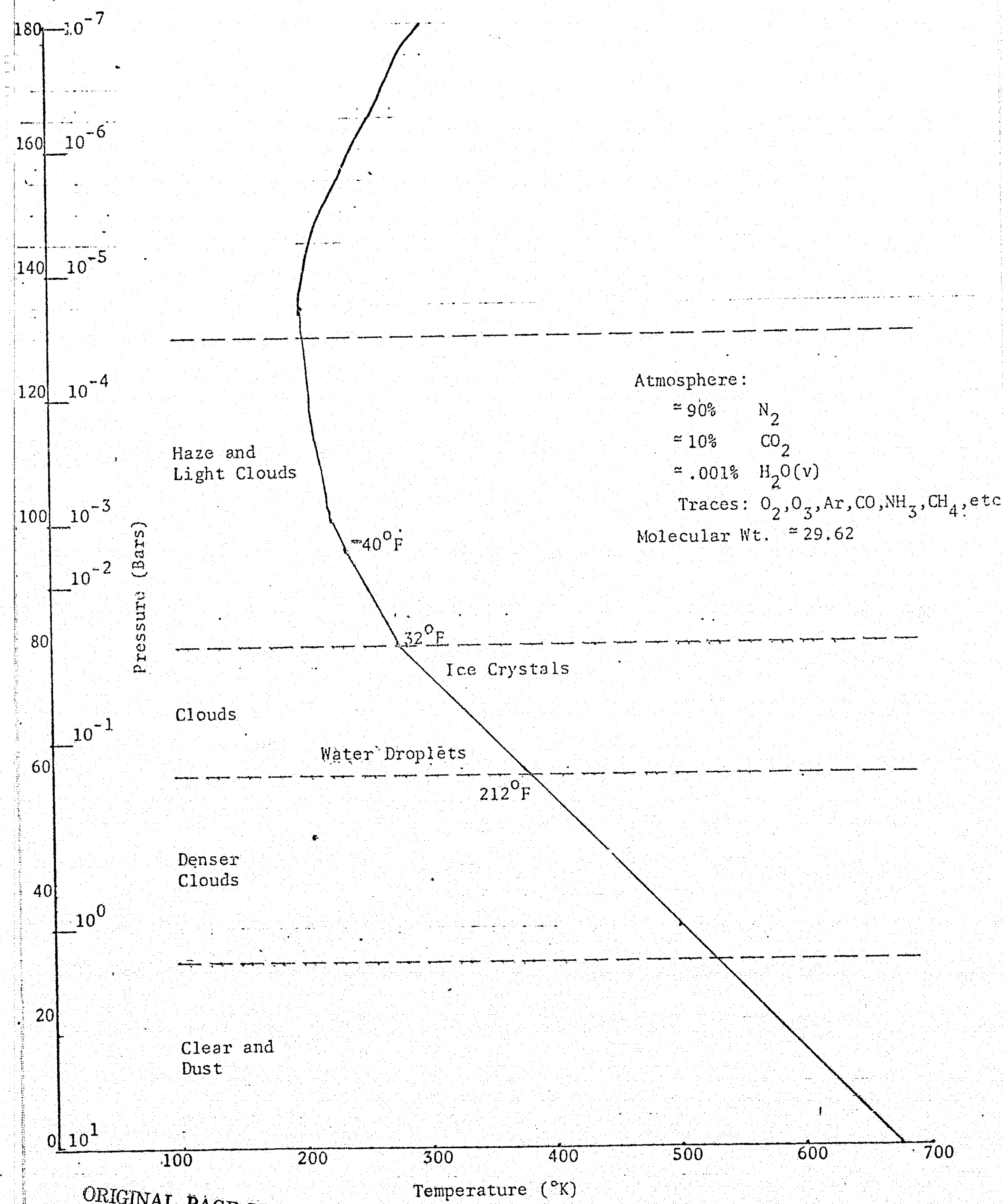

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FIGURE 1: THE ATMOSPHERE OF VENUS

C 2

3. Evolution of the Earth's Atmosphere

The Earth we live on today consists of minerals, rocks, soil, and organic liquids. It also contains a large quantity of liquid water and a deep gaseous atmosphere. One model for the evolution of our atmosphere has been proposed by Isaac Asimov[3/].

As solid matter conglomerated to form the Earth, it did so in a vast ocean of gas. Hydrogen predominated but other gases such as helium, neon, and argon - which do not ordinarily form compounds - were also present. There were also large quantities of oxygen, nitrogen, and gaseous carbon oxides. The Earth's gravity could not hold the lighter elements and, since they could not combine, they escaped into space.

The remaining elements combined into water vapor, ammonia, and methane gas. These gases constituted the original atmosphere of primordial Earth:

$H_2O(v)$: water vapor

NH_3: ammonia

CH_4: methane gas

This resembles the present atmospheres of the large outer planets which also contain vast quantities of hydrogen and helium.

This original atmosphere was gradually changed by the process of dissociation. Under the influence of ultraviolet light, the water vapor decomposed into hydrogen and oxygen,

$$H_2O(v) + \text{ultraviolet light} \longrightarrow [H] + [O]$$

The hydrogen could not be held by gravity and escaped into space. The oxygen combined with other elements of the atmosphere to form carbon dioxide, molecular nitrogen and water, that is,

$$[O] + CH_4 \longrightarrow CO_2 + H_2O$$

$$[O] + NH_3 \longrightarrow N_2 + H_2O$$

A new atmosphere was formed consisting of

$H_2O(v)$: water vapor

N_2: nitrogen gas

CO_2: carbon dioxide

This atmosphere resembles the present atmospheres of Mars and Venus. Mercury, like our Moon, was unable to retain any appreciable atmosphere.

1/ Isaac Asimov, Photosynthesis, Basic Books, 1968 - pgs. 168-174

Even though water vapor was still present in large quantities, dissociation could not continue. As oxygen began to accumulate in free form, some of it was converted into ozone, O_3. One of the properties of ozone is that it absorbs ultraviolet radiation, which is necessary for the dissociation process.

The Earth's atmosphere, in the absence of dissociation, did not remain static. The process of photosynthesis, to be described more fully later in the report, then took place.

Photosynthesis takes place under the energy of visible light, which is not screened out by ozone. Essentially, oxygen and hydrogen are formed out of water vapor by the action of visible light. The hydrogen is not liberated but is incorporated into plant tissue by the action of photosynthesis on carbon dioxide. Therefore, oxygen is produced and carbon dioxide is consumed according to the symbolic equation:

$$CO_2 + H_2O(v) + \text{visible light} \longrightarrow \text{organic matter} + O_2$$

Water vapor is restored to the atmosphere, since the plant tissue is eventually converted into water.

This process has resulted in our present atmosphere:

$H_2O(v)$: water vapor

N_2: nitrogen gas

O_2: molecular oxygen

The atmospheric evolution of the Earth is shown schematically in Figure 2.

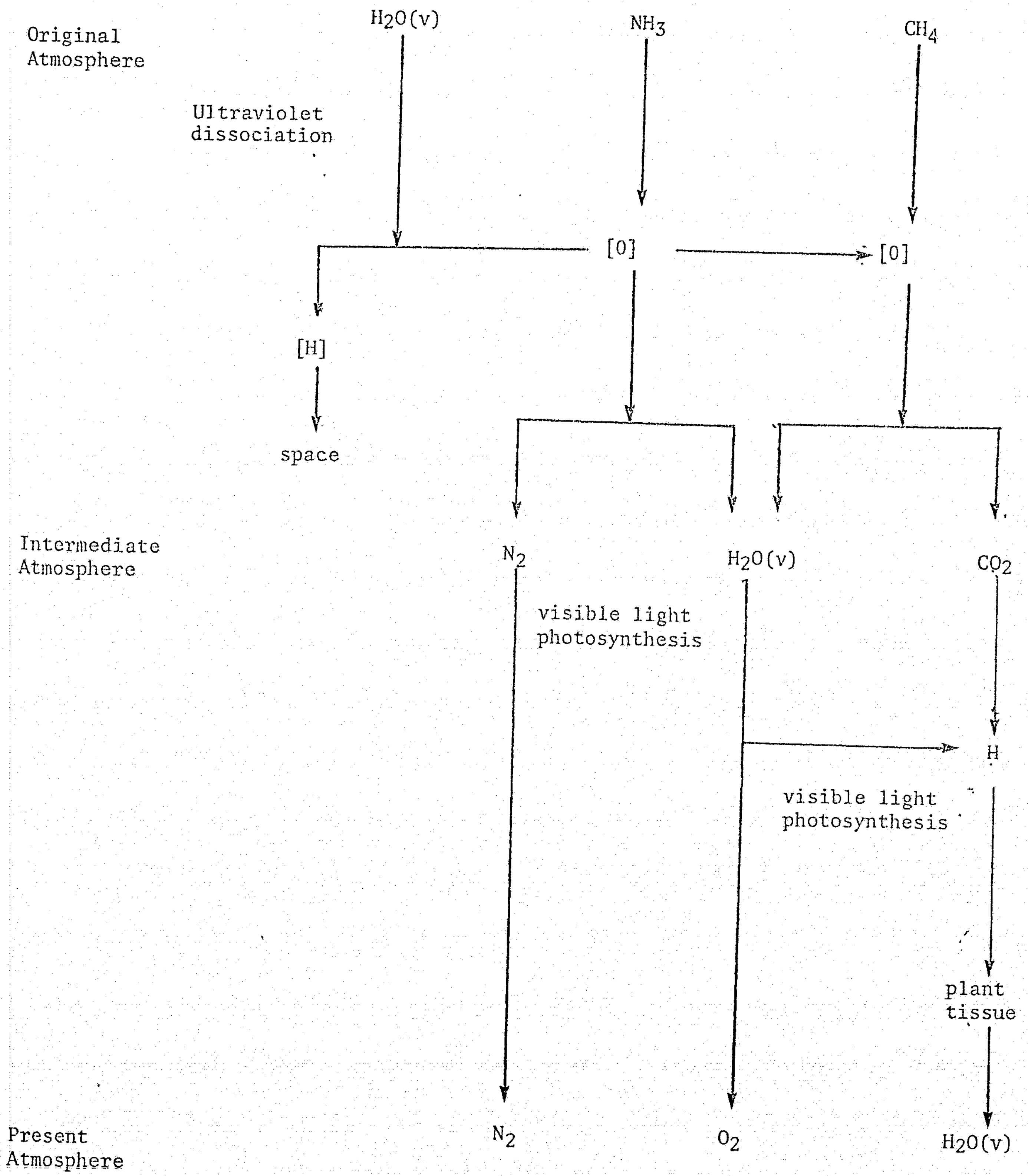

FIGURE 2: ATMOSPHERIC EVOLUTION OF THE EARTH

4. Photosynthesis

The process of photosynthesis has been taking place on Earth for millions of years, ever since plant life began. In this process the green parts of plants, when exposed to light under suitable conditions of temperature and water supply, use carbon dioxide from the atmosphere and release oxygen to it. As opposed to respiration, it takes place only in plants. Essentially, the process converts solar energy to chemical energy.

The necessary ingredients for photosynthesis are water, carbon dioxide, chlorophyll, and sunlight. It is a highly-complicated process, but for our purposes can be thought of as follows:

$$\text{water} + \text{carbon dioxide} + \text{light} \longrightarrow \text{oxygen} + \text{glucose}$$

or

$$H_2O(v) + CO_2 \xrightarrow{\text{photosynthesis}} O_2 + [HCOH],$$

where the term [HCOH] represents glucose and other hydrocarbons or sugars which, by other chemical reactions produce proteins, fats, and starches - foods for plants and animals.

The Carbon Cycle relating photosynthesis and respiration is shown schematically in Figure 3.

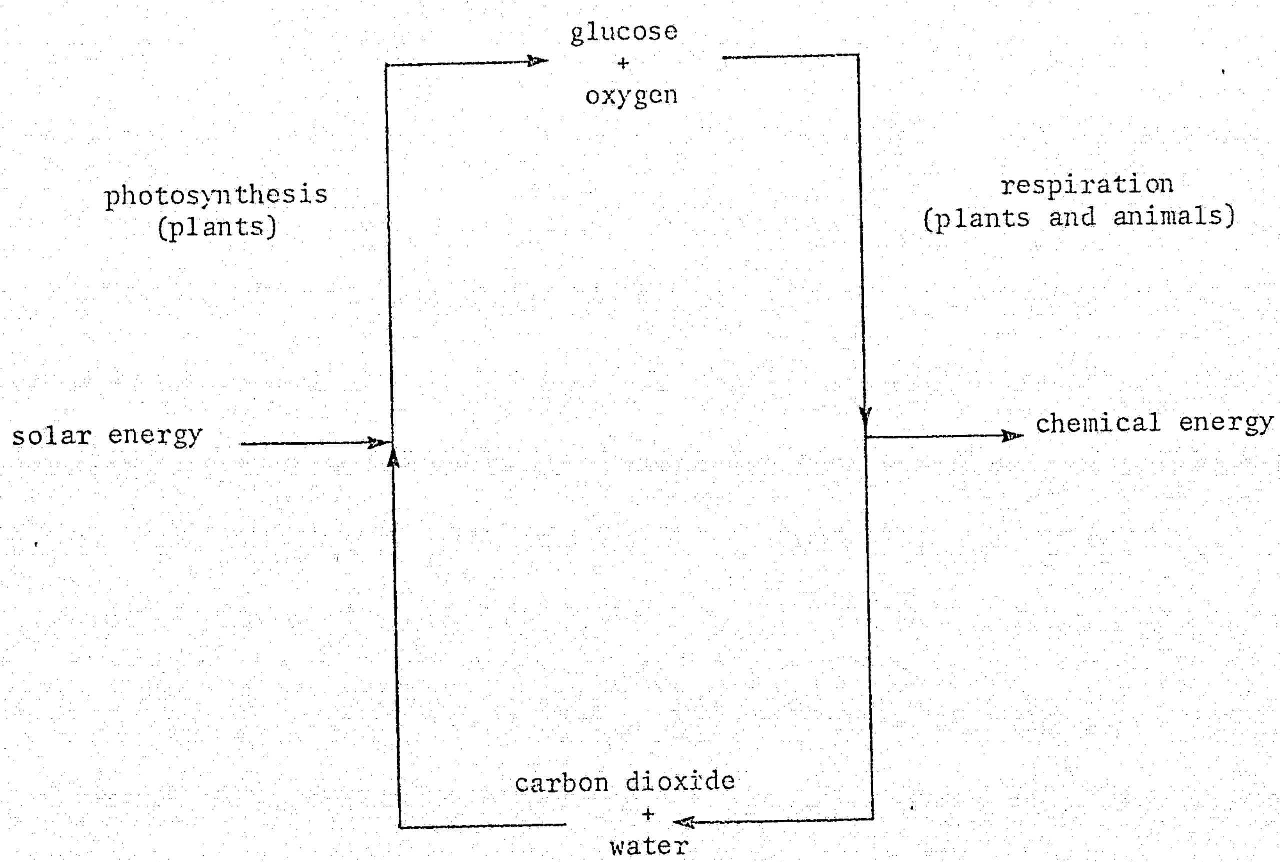

FIGURE 3: THE CARBON CYCLE

Photosynthesis takes place in chlorophyll-containing cells only when carbon dioxide, water, and light are available, and when a suitable temperature prevails.

Although carbon dioxide constitutes only 0.03% of the Earth's atmosphere, land plants are entirely dependent on this source. Experimentally, it has been shown that increasing the carbon dioxide concentration of an atmosphere results in an increased rate of photosynthesis.

The intensity, quality, and daily duration of sunlight all have an influence on the amount of photosynthesis taking place. In general, the longer the daily period of illumination the more photosynthesis will be accomplished by a plant in the course of a day.

A deficiency of water results in a reduced rate of photosynthesis.

The range of temperatures most suitable for relatively rapid rates of photosynthesis is not the same for all kinds of plants. Most photosynthesis in temperate zone plants occurs within the range of 10-35°C (50-95°F). An increase in temperature results in an increase of photosynthesis up to an optimum. With an increase in temperature above this optimum, the rate of photosynthesis decreases progressively.

For our purposes, the altering of the Venusian atmosphere, we are interested in the photosynthesis process as it applies to algae, principally certain blue-green algae.

5. Algae

Algae constitute one of the largest groups of animals or plant life. There are over 1,800 genera with over 21,000 different species. They are broken into eight groups based on color and other characteristics. As will be seen, the Cyanophyta, or blue-green algae, are of the most interest to us.

It is doubtful if any other groups of organisms on Earth live and grow in more numerous and diversified environments than do the algae. They are found in salt water as well as fresh water; some fresh water species are actually partly terrestrial. Algae are present in all oceans from the equator to near the poles. Some have been found in clear water at depths of more than 300 feet, while others have been found at alpine heights. Living spores of algae may be blown considerable distances by winds, and thus for intervals of time their abode is in the air.

Algae live by the process of photosynthesis which consists of the building up of sugar from carbon dioxide and water, by the aid of sunlight and green pigment, chlorophyll. This takes place in the following steps:

Step 1: The carbon dioxide is "fixed", that is, combined with some substance already in the cell.

Step 2: Photolysis takes place; light energy is used to break up water molecules. Oxygen is given off.

Step 3: The fixed carbon dioxide is reduced by the hydrogen obtained by photolysis.

Step 4: Phosphoglyceric acid is produced and, by a series of other reactions, yields sugar.

The chlorophyll makes the light energy available to drive this chemical process, which is

$$6CO_2 + 12H_2O \xrightarrow{\text{light}} 6O_2 + 6H_2O + C_6H_{12}O_6$$

H_2O is on both sides of the equation to indicate that the oxygen given off as a by-product comes entirely from water and not from the carbon dioxide.

In addition to the carbon dioxide and water needed for photosynthesis, algae, like other plants, require a variety of other mineral substances and elements. One can get an idea of these needs by burning the algae and analyzing the residue. The same elements as higher plants such as nitrogen, phosphorus, sulphur, potassium, calcium, magnesium, and iron are present with traces of copper, boron, manganese, zinc and cobalt. Algae are quite versatile in their nutritional requirements and can use a wide range of inorganic and organic sources. Usually, the supply of minerals presents no problems, especially with marine algae, although a lack of nitrogen or phosphorus can limit their growth.

Sexual processes vary widely from species to species. Sexuality requires periodicity of light, optimum temperatures, the depletion of nitrogen in the culture medium, and abundant carbon dioxide. There appears to be no sexual process in any member of the blue-green group.

6. Cyanophyta (Blue-green Algae)

The Cyanophyta are a very primitive group of algae; most of them have changed little, if at all, for many millenia. There are today about 150 genera, containing something like 1,500 species, with a very varied distribution. Some of them live in the sea, many more inhabit fresh water, and there are also many common species that live in the soil. They are all microscopic and unicellular, but do form colonies. They show many differences in organization from the other algae. We shall highlight those differences - reproduction process, nitrogen-fixing ability, and temperature resistance - which pertain to the problem of altering the Venusian atmosphere.

The blue-green algae have no flagellated reproductive cells; there appears to be no sexual process in any member of the group. Reproduction is very simple. The normal method is by cell division, where the two daughter cells may remain fixed to each other by a common gelatinous envelope. Therefore, rapid cell division can result in a colony of many cells. The rate of reproduction is a matter for a great deal of study; under certain ideal conditions, it has been shown that the number of individuals may increase 50- to 100- fold in a week.

Some blue-green algae, principally Nostoc, have the ability to "fix" atmospheric nitrogen, that is, to cause nitrogen from the atmosphere to combine to form compounds that are available for nourishment of itself and other plants. Lately, laboratory experiments have convincingly shown that Nostoc can grow in a culture solution that does not contain any nitrogen compounds and, moreover, combined nitrogen appeared in the medium after they had been growing for a time.

Although Nostoc and certain other blue-green algae have been shown to fix atmospheric nitrogen under experimental conditions, it is still doubtful how much they fix, if any, in nature. These experiments appear to indicate that they do not fix atmospheric nitrogen if they are supplied with nitrogen in the form of nitrates or ammonium salts as an alternative. However, no other plants, and only a few species of bacteria, have been shown to have the ability to fix atmospheric nitrogen at all.

Certain algae, mainly blue-green, flourish in a wide range of temperatures. Species of Cynophyta have been found that live in hot springs at temperatures which would be lethal to all other plants except certain bacteria. The record is about 85°C (185°F), approaching the boiling point of water. 163 species of heat-tolerant algae have been found in Yellowstone Park alone. The fact that blue-green algae grows at higher temperatures than most other organisms is unexplained.

Many Cyanophyta give rise to spores called akinites. These consist of cells in which there has been an accumulation of food reserves; the cell usually enlarges and develops a thicker wall. They appear to be resting spores which enable the algae to survive unfavorable periods, and usually they germinate, giving rise to new filaments, when things become more favorable. They have been known to remain dormant but viable for as long as seventy years.

7. Technical Summary

It appears that the atmosphere of Venus, as presently understood, has the ingredients to support photosynthesis. There is certainly enough carbon dioxide; the presence of sufficient water vapor in usable form has yet to be established. The temperatures at certain levels are suitable for the process.

It seems feasible that a strain of blue-green algae can be developed that would live and flourish at certain levels in the Venusian atmosphere. The density of the atmosphere and the resulting convective currents would probably keep the algae airborne long enough to achieve measurable results.

How long such a process would require is unknown. It seems that once there has been partial penetration of the "greenhouse sphere" the process would be speeded up.

Program Description and Costs

Subject to a great amount of further study, experimentation, and data-gathering missions it would appear that a planetary engineering project to alter the atmospheric and surface characteristics of Venus and thus the planet's ability to support man, animals, and plant life is feasible. It may be possible to achieve perceivable alterations within a century.

Such a program would have three major thrust areas:

- laboratory experimentation of algae, photosynthesis, model atmosphere, and their interactions
- probes and other missions to further determine the atmospheric profiles of Venus and other bodies
- algae-seeding missions to test the concepts leading to the conduct of actual operations

1. Experimentation

Studies and laboratory experimentation on the properties of algae and their capability for supporting photosynthesis in alien atmospheres would be required.

Chambers would be developed and instrumented wherein various model atmospheres can be created and tests conducted to measure the ability of algae to flourish in such atmospheres.

New strains of algae will be developed, possibly over decades, with the necessary characteristics to photosynthesize in such atmospheres. Their need for minerals and other substances not present in these model atmospheres must be minimized. The ability of these algae to fix nitrogen must be further investigated and developed.

The processes of photosynthesis and respiration, that is, the carbon cycle, must be a subject for study and experimentation to support this program and other terrestrial needs.

Quantification of these results should demonstrate the feasibility of the total program.

This part of the program should start within a year or two. The approximate costs would be as follows:

- $1M for program definition (approximately one year).
- $5M per year for about five years to support initial laboratory studies and experimentation in the form of grants to universities and other agencies and organizations.
- $10M per year for about three years to support the development of the chambers and required instrumentation.
- $100-150M for the production and implementation of chamber facilities.
- $10-15M per year for continuing studies.

Over the first ten years, the cost of this part of the program would be approximately $200-250M.

2. Space Missions

This portion of the program would involve refined spectroscopic analyses from Earth-orbiting spacecraft; probes into the atmosphere of Venus; and Venus fly-bys and orbital missions. The probes would be required to support this program directly. Atmospheric studies would be a part of the experimentation carried by other missions.

The objectives would be to define the characteristics at all levels of the atmosphere of Venus and the surface itself. Specifically:

- the surface temperatures at specific locations,
- the presence of gaseous elements - specifically carbon dioxide, water vapor, oxygen, and nitrogen at all levels,
- the presence of mineral elements on the surface and in the Venusian atmosphere,
- atmospheric temperatures and densities at all levels as well as their seasonal changes,
- identification of any life forms in the atmosphere or on the surface.

The purpose would be to define the atmosphere of Venus in order to support terrestrial experimentation, operational tests, and the conduct of the final program itself.

This part of the program could extend over many decades, each step further refining our knowledge. Costs can only be grossly estimated as follows:

- 10 atmospheric and surface probes at $100M each.
- Additional instrumentation for other planned missions: $500M
- Reduction of data: $100M
- Launch costs: $400M

These activities, over a thirty year period should cost less than two billion dollars.

3. Operational Tests and Seeding Missions

With the lack of quantification, it is difficult to assess this final part of the program. It is impossible at this time to estimate the complexity of each mission, the number required, and the number of years before results are obtainable.

It is felt that the spacecraft themselves need not be more complex than those presently in use. The algae-carrying compartments need only carry the algae and the necessary materials and equipment to sustain life until they are deployed. Present navigation and guidance systems would be satisfactory. Refined altimeters to separate the algae cultures at the proper altitudes would be required.

The costs associated with this portion of the program can only be estimated as the first two phases proceed. However, it is felt that the costs of the entire program would be less than the costs associated with the Apollo lunar landing program.

Relationship to National Needs

This program would support most of the National Needs.

New Knowledge would be gained in several areas

- characteristics and life processes of algae
- photosynthesis and respiration
- atmospheres of the Earth and other planets

The development of Food and Other Natural Resources would be enhanced through knowledge gained on algae, photosynthesis, and respiration.

The knowledge gained in the atmospheric studies would enhance our ability to control our own Environment and thus aid in the Protection of Life and Property.

The studies of the carbon cycle may yield new methods for the creation of, harnessing of, or conservation of Energy.

The Economy would be benefitted by

- the number of people and facilities devoted to the project
- potential benefits to agriculture
- possible breakthroughs in environmental control

Relationship to NASA/OAST Space Technology Goals

In the short term, up to the year 2000, no significant increases in space technology systems would be required except for development of new sensors and instrumentation for atmospheric probes. Ultimately, we will need to improve our capability for placing large payloads in planetary orbits at low costs per pound

Summary and Conclusions

- The ability of man to alter the atmosphere and surface of Venus so that the planet will sustain human, animal, and plant life appears to be feasible.

- Such a development may, in the next millenium, be required for the further existence of the human race.

- The seeding of the Venusian atmosphere with certain spores of blue-green algae, with supporting photosynthesis, seems to be the most feasible way to affect the changes.

- The costs of starting such a project would be minimal for several years. The entire project costs should be somewhat less than $20 B dollars.

- It is recommended that the first phase, laboratory studies and experimentation be started in the near future. The further implemenattion of the program would take place at an appropriate time.

PLANETARY EXPLORATION

TABLE OF CONTENTS

Application: Planetary Exploration

Background:

One of the continuing goals of intelligent man has been to understand the Solar System and to unlock the secrets of the Universe. This search started in prehistory, was continued by the Ancients, and has culminated in the amazing discoveries of the last few centuries.

Prehistoric man started to find some answers. He early recognized that the presence or absence of the Sun significantly affected his life. He could carry out hunting, fishing, and other outside pursuits during the day, but he was compelled to return to his cave or huddle around a campfire at night. He soon learned that the heat of the Sun, varying from season to season, had a great effect on his crops. Early coastal men probably realized that the positions of the Sun and Moon governed the ebb and flow of the tides.

The Ancients were more curious. Although they continued and expanded the studies of the effects of heavenly bodies on terrestrial events, their philosophers became interested in the less pragmatic relationships between the Earth and the other objects they could see in the sky. They began to wonder about their distances and sizes as well as their movements with respect to the Earth and each other. Finally, they tried but failed to formulate the physical laws that governed the system. They had the intelligence but lacked the observational tools and measurement devices that have since been developed.

The first dimension in the Solar System known to man was the size of the Earth. This was determined in about 230 B.C. by Eratosthenes, a Greek philosopher. Knowing that the Earth was spherical and having determined that the angle between the Earth's equatorial plane and the ecliptic was about $23\frac{1}{2}^{o}$, the latitude of Syene (now Aswan); he measured the angle of a shadow cast by a stake driven vertically into the ground at Alexandria at noon on the day of the summer solstice. Applying elementary trigonometry, he calculated the circumference of the Earth. The value he obtained was within one percent of the presently accepted value.

In planetary, exploration there were no significant accomplishments for many centuries. Further progress required more accurate measurement devices and the invention of the telescope. Developments during the 16th and 17th centuries made it possible for astronomers and mathematicians to determine many of the dimensional characteristics of the Solar System, and the interactions of the planets with the Sun, and each other.

The Copernican theory gradually gained acceptance by the scientific world. Galileo first trained a telescope on heavenly bodies -- among other things he discovered that Jupiter had four moons revolving about it; a Solar System in miniature. Tycho Brake's painstaking observations and extensive catalogs and records of the planets, enabled the analysis of his pupil Kepler which led to the formulation of his three laws of planetary motion. Isaac Newton in his Principia developed the basic principles of celestial mechanics, formulated the laws of motion and the Law of Universal Gravitation, and described mathematically the nature of motions in the Universe.

The work of these giants enabled other scientists gradually to determine the masses, sizes, and densities of the Sun, Earth, Moon and known planets; to calculate the orbital characteristics of all known bodies in the Solar System; and to completely map the Solar System in terms of the Astronomical Unit. Therefore, whenever any one distance is accurately determined, all the others can be calculated and refined.

The mathematicians Gauss, Lagrange, Laplace and others developed the theory of celestial mechanics which, with refinements, is still valid and used today. Comets appeared and reappeared; celestial mechanics showed that they were, indeed, part of the Solar System.

New objects were found. Many asteroids were found, largely in orbits between Mars and Jupiter. A new planet, Uranus, was discovered by telescope. Calculations based on perturbations of the orbit of Uranus led to the discovery of Neptune. The outermost known planet, Pluto, was found in 1930. Many of the planets were found to have satellites ranging in size from Mar's Deimos, a small rock, to Jupiter's huge satellite, Ganymede, even larger than the planet Mercury.

The physical dimensions of objects in the Solar System, the distances between them, their motions, and their interactions are well known. Other planetary characteristics are not as fully understood: the chemical compositions of their interiors, surfaces, and atmospheres; the presence or absence of magnetic fields; seismic activity; subsurface heat flow; and their meteorological characteristics.

Optical and radar observations, with careful analyses, have yielded a great deal of information. Ground-based spectrographic studies have given us important clues as to the chemical compositions of the planets but the screening out of important radiation by our own atmosphere severely limited the validity of the results. Observational instruments that have been placed in Earth orbit have greatly improved this aspect.

However, space technology has given us the tools to enable us to carry out an extensive study of the planets during the next few decades. Possibly by the middle of the next century, we will know almost as much about the planets, at least those of greatest interest, as we now know of the Earth and Moon. One great spur to planetary exploration, from the scientific viewpoint, is the fact that they are so remarkably different from each other.

Objective:

The purpose of this program will be to dramatically increase mankind's knowledge of the planets in the Solar System over the next few decades with a view to an almost-complete understanding by the middle of the next century. Planetary exploitation will follow whenever justified by these discoveries.

The program will yield

- knowledge of the physical and chemical structures of planetary surfaces and interiors

- a determination of their geological ages
- measurements of the presence or absence of magnetic fields and seismic activity, as well as internal heat flow characteristics
- understanding of planetary atmospheres: their chemical structure at all levels, their dynamic flow patterns, the degree of ionization, and the presence of pollutant materials.
- knowledge of the meteorological characteristics and their relation to those of the Earth, for potential exploitation
- detection of the presence of fossil or present life forms and a more complete understanding of the development of life
- an evolutionary model of the planets and their satellites.

Program Description:

The NASA Office of Space Sciences has adopted a three-phased approach to planetary exploration. These phases are:

- Reconnaissance
- Exploration
- Intensive Study

During the reconnaissance phase, first looks are taken at all the planets and their satellites with instruments capable of determining their gross properties and to establish the approach to the exploration phase. The intensive study phase is concerned with very accurate in-depth measurements of important characteristics.

This is analogous to the accomplishment of the lunar program. The reconnaissance phase was performed with the Ranger spacecraft which sent back the first closeup photographs of the lunar surface. The exploration phase was accomplished by the Lunar Orbiter and Surveyor Programs. The Orbiter series photographed almost all of the lunar surface and the Surveyors soft landed, sent back closeups of the lunar surface, determined the chemical composition using an alpha-scattering device, and sampled the lunar soil with digging/scooping apparatus. The intensive study phase corresponded to the Apollo missions. Samples were returned to Earth and subjected to detailed analysis in laboratories all around the world. Lunar surface experiment packages were deployed by the astronauts and transmitted masses of data back to Earth. These data have also been subjected to intense analysis.

In the Viking program we are, at this writing, performing the exploration phase.

The strategy for planetary exploration calls for completion of the reconnaissance phase, already well under way, and the exploration phases before the end of the century. The intensive study phase will be well under way by this time. The 21st century will see a continuation of the intensive study phase and exploitation and colonization of certain other planets and their satellites.

An OAST/OSS potential schedule for a phased approach to planetary exploration and exploitation is depicted in Figure 1.

Ground-based observations, with improved instruments, will continue to play an important role in the reconnaissance phase of the program. Earth-orbiting instruments will also add to the fund of knowledge. Information gained from flyby spacecraft, equipped for photography and using other sensor systems, as well as probes -- possibly deployed from the flyby spacecraft -- will aid in the design of spacecraft and instrumentation for the exploration phase.

The exploration phase will make use of orbiting spacecraft, atmospheric entry probes, and surface penetrators. The orbiter observation times will be many months in duration.

The intensive study phase will utilize orbiters and soft landers with sampling and sample screening equipment. The potential exists for automated systems that will return selected samples either to Earth or to an automated planetary space station (APSS).

The APSS systems represent a series of complex planet-orbiting laboratories. They will serve as orbiting observatories. They will serve as launching platforms for deployment of surface rovers which will be used for surface observation, analysis, and sample acquisition. The rovers will be able to return selected samples to the APSS for more sophisticated automated analysis. Capability for returning samples to Earth will also be available. APSS systems will have observational lifetimes measured in years.

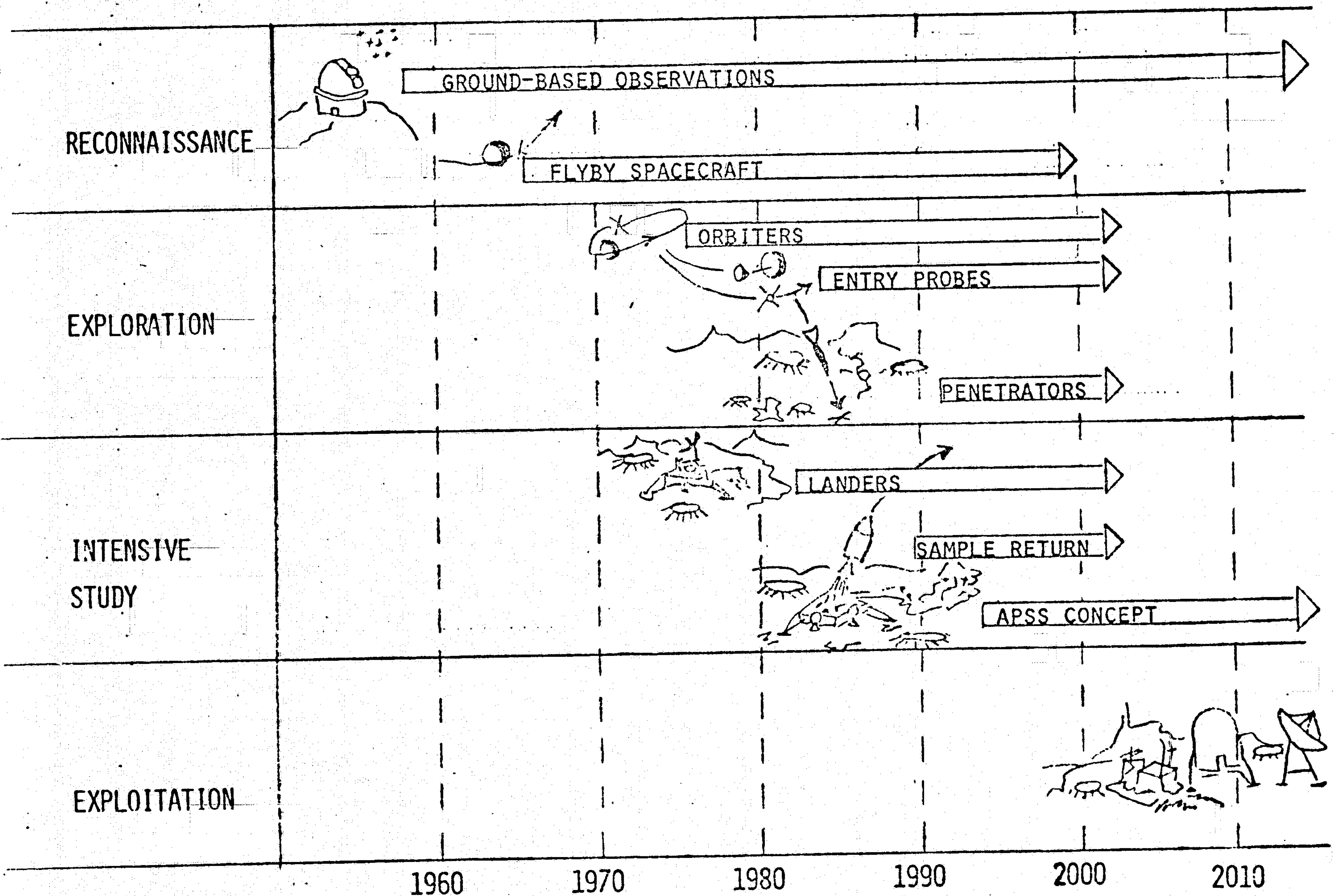

FIGURE 1: PHASED APPROACH TO PLANETARY EXPLORATION

Supporting Space Technology:

A comprehensive planetary exploration program will require significant but attainable advances in space technology. The achievement of the NASA/OAST Space Technology Goals as further detailed in the Forecast of Space Technology, with increased emphasis on reliability considerations, would meet the objectives of this ambitious program.

Relatively heavy spacecraft-payload combinations, of several thousand kilograms, with operating lifetimes of up to twenty years, will travel over great distances -- the planet Pluto is over three billion miles away.

Considering the great distances involved, there will be a need for nuclear propulsion capability so that thrust can be applied throughout the journey.

As a spacecraft moves away from the Sun toward the outer planets the use of solar energy for spacecraft power is lost. Larger and improved radioisotope thermal generators will be needed.

Communication time lags will be prohibitive (over ten hours in the case of Pluto). Therefore on-board systems must be autonomous to a degree not heretofore approached.

The sensors used in the planetary exploration program will be similar to those that have been used in earth-orbital missions and in previous planetary flybys but will be much more sophisticated.

Sophisticated information management will be one of the keys to the success of this program. Only the data that the scientist needs should be transmitted to Earth and then in the format he can readily use. Refined on-board data processing equipment will be required along with highly-efficient data selection and compression capability.

Reliability of the highest degree will be required for these long-life systems. At least triple-redundance and self-repair capability should be required for electronic systems. An extensive test program will be instituted.

Socio-Economic Benefits:

There will be no attempt to quantify socio-economic benefits for this application. Nor will we discuss thoroughly the purposes and advantages of such a program. A very fine discussion has been presented in Exploration of the Solar System NASA EP-122, pgs. 2-6.

The great benefits of a planetary exploration program are:

1. Exploration

The desire to explore is one of the driving forces of mankind. Through the years explorers have been among the most admired of individuals. Through the centuries the voyages to the New World, the attempts to reach the poles and to scale the highest mountains, and to conquer the air have always captured the imagination of the public. The adventurous type of exploration NASA has been engaged in has had great popular appeal. The Apollo program was avidly followed by people in all walks of life, throughout the world. Successful endeavors in planetary exploration will add greatly to the prestige of nations and groups performing them.

2. Science

Man has a desire to gain new knowledge in all scientific areas. Often the drive is for knowledge for knowledge's sake. However, advances in science have led to improvements in all areas of human existence and activity. Most frequently, the advantages to be gained were not apparent when the scientific quest began. We cannot, at this time, enumerate the benefits that will accrue from a planetary exploration program -- but we know they will be there.

3. Advanced Technology

Advanced technology will be needed, as was seen in the preceding section, for many aspects of the planetary exploration program. This same technolgy will be required and used in many other areas of space activity. As has proved to be the case through the years, these technological advances will be useful in many other fields as well.

4. Economic Growth

Expanding science and technology lead to economic benefits. A planetary exploration program will be of direct economic benefit to many industries: aerospace, electronics, data processing, communications, energy production, to name a few. University research programs will expand. New facilities will be required in certain areas; the resulting industrial growth will benefit many communities.

In addition to direct economic benefits, this program, as has been the case in other large-scale space endeavors, will act as a spur to the economy in general.

5. Forerunner for Exploitation

Our knowledge and understanding of the other planets in the Solar System will enable us to exploit these natural resources for the benefit of mankind.

A planetary exploration program can be an important part of a weather prediction and modification program. The effects of varying gravitational fields on climate can be studied on other planets. Similarly, the effects of slow rotation, as is the case of Venus, on climate will be studied using the planet itself as the laboratory. Weather modification techniques and other potentially hazardous activities can be tested on other planets or satellites.

Summary and Conclusions

- A three-phase planetary exploration program is needed over the next few decades
- The first phase, reconnaisance, already under way, will be completed before the end of the century
- The exploration phase will also be completed by the end of the century
- The intensive study phase will be underway by this time
- During the twenty-first century the intensive study phase will continue, and exploitation and colonization of certain planets and satellites will proceed.

V Summary

Separate examination of the six selected space system applications was appropriate for developing necessary background information and system descriptions, from which to define and quantify -- where possible -- the potential socio-economic benefits. The six system applications are presented as case studies in the preceding chapter, to facilitate separate distribution.

Nevertheless, the case study format does not demonstrate adequately the extent to which these system applications complement each other in the support of National Needs or in the generality of potential benefits. Table 1 summarizes the potential socio-economic benefits of the six system applications -- in terms of National Needs and NASA Themes.

The six systems will make beneficial contributions in support of all seven National Needs. Potential economic benefits will be pervasive, extending beyond the first-order effects described in this study. Important contributions to solution of our energy and environmental problems can be expected. Widespread and large benefits will accrue through improved protective and forecasting systems. Similarly, contributions to New Knowledge and Defense Needs will be diverse.

In addition, pairs of the six system applications are complementary. For examples, consider the electronic mail and personal telephone systems, the weather-climate and crop-water forecasting systems, and the planetary systems. Undertaking one of a pair will enhance the potential of its complement.

These selected space system applications may be summarized as offering potentially very great socio-economic benefits for the basic needs of our society. They also indicate the potential contributions of other system applications yet to be examined in comparable detail.

NATIONAL NEEDS

SYSTEM APPLICATIONS	ECONOMY	ENERGY	ENVIRONMENT	PROTECTION OF LIFE AND PROPERTY
ELECTRONIC MAIL NASA Theme: Global Service Systems	• Enlarged industrial base • Customer savings • Increased USPS revenues • USPS savings in operational costs • Impact on paper and recycling industries • Less misdirected mail	• Reduction in use of ground transportation fuels • Reduction in use of aircraft fuels • Recovery of energy from recycling operations	• Less pollution due to air and ground transportation	• More rapid dissemination of information • Less lost and misdirected mail
PERSONAL TELEPHONE COMMUNICATIONS NASA Theme: Global Service Systems	• Enlarged industrial base • Less cost per call • More rapid industrial communications • Development and sale of new products	• Less ground electrical energy required • Solar energy on satellite self-generated	• Less pollution due to reduced need for electrical energy	• Search and rescue operations facilitated • Reduced law enforcement and fire response times • Rapid warning of natural phenomena threats • Rapid transmission for medical/surgical use
WEATHER AND CLIMATE MONITORING, PREDICTION, AND CONTROL NASA Theme: Global Service Systems	• Enlarged industrial base • Increased food supply • Increased world markets • Savings to property • Reduced transportation costs • Improvements in industrial facilities	• Potential new energy sources - winds, tidal, solar • Savings in use of present resources	• Prediction of pollution effects • Atmospheric modification	• Natural phenomena prediction • World transportation safety enhanced • Protection of Range animals • Protection of wild animals
CROP PRODUCTION FORECASTING AND WATER AVAILABILITY NASA Theme: Global Service Systems	• Enlarged industrial base • Reduced crop losses • Improvement in land and crop management • Increased trade • New and improved water sources	• Encourage use of new sources • Increase production of hydroelectric power • Reduce power requirements through improved machinery usage	• Better management of air and water resources • Reduction of pollution	• Reduced crop losses • Improved animal husbandry due to drought prediction • Ability to eliminate starvation
PLANETARY ENGINEERING OF VENUS NASA Theme: Exploration of the Solar System	• Enlarged industrial base • Colonization effects on the economy • Potential benefits to agriculture	• New methods for the creation of, harnessing of, or conservation of energy	• Ability to improve the earth's ecosphere • Weather modification	• Possible survival of humanity • Colonization because of overpopulation • Control of our own environment
PLANETARY EXPLORATION NASA Theme: Exploration of the Solar System	• Enlarged industrial base • Increase in university research facilities • Potential new resources	• New methods for the creation of, harnessing of, or conservation of energy	• Ability to impi ve the earth's ecosphere • Weather modification experiment's on other bodies	• Possible sources for colonization

TABLE 1 - SUMMARY OF POTENTIAL BENEFITS FROM SELECTED SPACE SYSTEM APPLICAT

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NATIONAL NEEDS

	PROTECTION OF LIFE AND PROPERTY	FOOD AND NATURAL RESOURCES	NEW KNOWLEDGE	DEFENSE
	• More rapid dissemination of information • Less lost and misdirected mail	• Increase in recycling facilities • More timber use	• Potential of large space structures • Improvements in electronics, communications, and data processing • Accumulation of data on wave propogation	• Improved facilities for routine mail • Potential for station-to-station classified use
ical	• Search and rescue operations facilitated • Reduced law enforcement and fire response times • Rapid warning of natural phenomena threats • Rapid transmission for medical/surgical use	• Decreased use of metal resources • Small decrease in timber requirements	• Use of large space structures • Improvements in electronics, communications, and data processing • Accumulation of data on wave propogation	• Rapid communications between bases and to field installations • Less vulnerable system to storms, etc.
n	• Natural phenomena prediction • World transportation safety enhanced • Protection of Range animals • Protection of wild animals	• Protection of resources • Crop insurance-reduced damage • Better crop and animal husbandry • Transportation planning	• More complete understanding of weather and climate • Better knowledge of the atmosphere • Improved math models and the use of data processing	• Knowledge for better military planning • Weather modification as a defense tool
r	• Reduced crop losses • Improved animal husbandry due to drought prediction • Ability to eliminate starvation	• Greater food supply • Improved land and water management • Use of ocean resources	• Improved knowledge of photosynthesis • Use of ocean resources • Math modeling and data processing	• Knowledge for better military planning
	• Possible survival of humanity • Colonization because of overpopulation • Control of our own environment	• Need for additional natural resources • Improved agricultural productivity on Earth	• Potential of weather modification • Improved knowledge of photosynthesis and respiration • Studies of algae characteristics • Planetary Atmospheres • Laboratory chambers and math modeling	• Potential of weather modification as a defense tool
	• Possible sources for colonization	• Potential for new resources	• Physical and chemical structures • Planetary atmospheres • Planetary meteorology • Detection of life forms • Modeling and data processing procedures	• Potential of weather modification as a defense tool

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